Geomorphology

Climatology

Climatic Regions

Oceanography

Indian Geography

Economic Geography

Geomorphology

Interior Of The Earth

- The configuration of the surface of the earth is largely a product of the processes operating in the interior of the earth.
- **Exogenic** as well as **endogenic** processes are constantly shaping the landscape.

Why know about earth's interior

Understanding of the earth's interior is essential to understand the **nature of changes that take place over and below the earth's surface.**

- To understand geophysical phenomenon like volcanism, earthquakes etc..
- To understand the internal structure of various solar system objects
- To understand the evolution and present composition of atmosphere
- Future deep-sea mineral exploration etc.

Sources of information about the interior

Direct Sources

- Deep earth mining and drilling reveals the nature of rocks deep down the surface. [**Mponeng gold mine and TauTona gold mine in South Africa are deepest mines** reaching to a depth of 3.9 km. And the deepest drilling is about 12 km deep]
- **Volcanic eruption** forms another source of obtaining direct information.

Mponeng mine

South Africa
Deepest mine
Gold mine
Deapth: 2.4 miles (3.9 km)

Indirect Sources

- **Depth:** With depth, pressure and density increases and hence temperature. This is mainly due to gravitation.
- **Meteors:** Meteors and Earth are solar system objects that are born from the same nebular cloud. Thus they are likely to have a similar internal structure.
- **Gravitation:** The gravitation force (g) is not the same at different latitudes on the surface. It is **greater near the poles and less at the equator**. This is because of the distance from the center at the equator being greater than that at the poles.
- The gravity values also differ according to the mass of material. The uneven distribution of mass of material within the earth influences this value. Such a difference is called **gravity anomaly.** Gravity anomalies give us information about the distribution of mass of the material in the crust of the earth.
- **Magnetic field:** The **geodynamo effect** helps scientists understand what's happening inside the Earth's core. Shifts in the magnetic field also provide clues to the inaccessible iron core. But their source remains a mystery.

***Not important for exam**. But if you are a science enthusiast and if you want to know more…*

What causes the magnetic field of earth?

Our planet's magnetic field is believed to be generated deep down in the Earth's core.

Nobody has ever taken the mythical journey to the centre of the Earth, but by studying the way shockwaves from earthquakes travel through the planet, physicists have been able to work out its likely structure.

Right at the heart of the Earth is a solid inner core, two thirds of the size of the Moon and composed primarily of iron. At a hellish 5,700°C, this iron is as hot as the Sun's surface, but the crushing pressure caused by gravity prevents it from becoming liquid.

Surrounding this is the outer core, a 2,000 km thick layer of iron, nickel, and small quantities of other metals. Lower pressure than the inner core means the metal here is fluid.

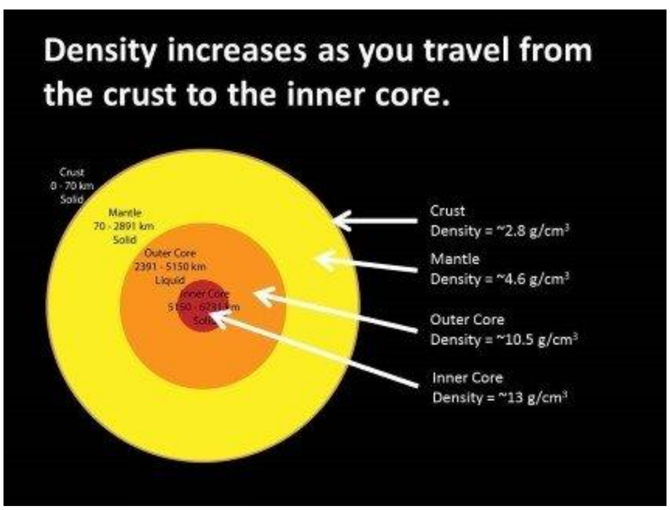
Differences in temperature, pressure and composition within the outer core cause convection currents in the molten metal as cool, dense matter sinks whilst warm, less dense matter rises. The Coriolis force, resulting from the Earth's spin, also causes swirling whirlpools.

This flow of liquid iron generates electric currents, which in turn produce magnetic fields. Charged metals passing through these fields go on to create electric currents of their own, and so the cycle continues. This self-sustaining loop is known as the **geodynamo.**

The spiraling caused by the Coriolis force means that separate magnetic fields created are roughly aligned in the same direction, their combined effect adding up to produce one vast magnetic field engulfing the planet.

Some sources explained in detail

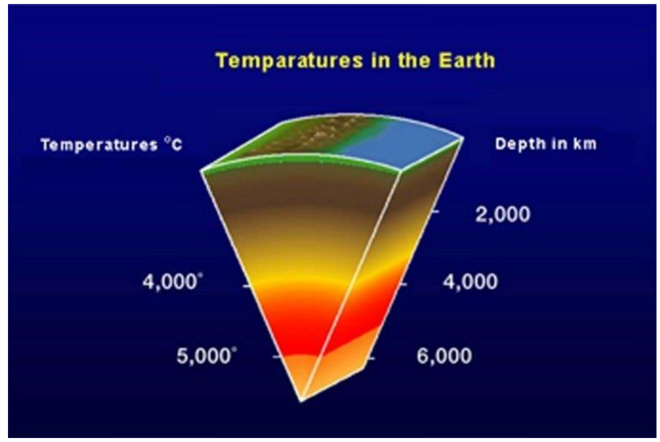
High Levels of Temperature and Pressure Downwards



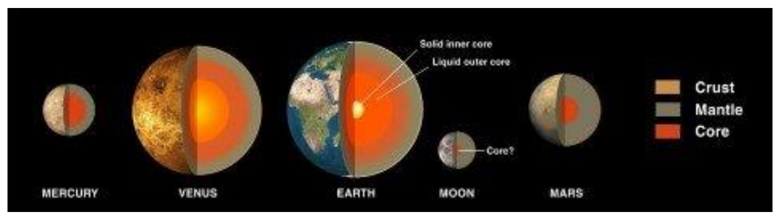
- **Volcanic eruptions** and existence of hot **springs, geysers** etc. point to an interior which is very hot.
- The high temperatures are attributed to **automatic disintegration of the radioactive substances.**
- **Gravitation** and the diameter of the earth helps in estimating pressures deep inside.

Evidence From The Meteorites

- When they fall to earth, their outer layer is burnt during their fall due to extreme friction and the inner core is exposed.



- The heavy material composition of their cores confirms the similar composition of



the inner core of the earth, as both evolved from the same star system in the remote past.

- The most important indirect source is seismic activity. The major understanding of the earth's internal structure is mainly from the study of seismic waves.

Seismic waves

- The study of seismic waves provides a complete picture of the layered interior.

What causes earthquakes?

- Abrupt release of energy along a fault causes earthquake waves.
- A fault is a sharp break in the crustal rock layer.
- Rocks along a fault tend to move in opposite directions. But the friction exerted by the overlying rock strata prevents the movement of rock layer. With time pressure builds up.

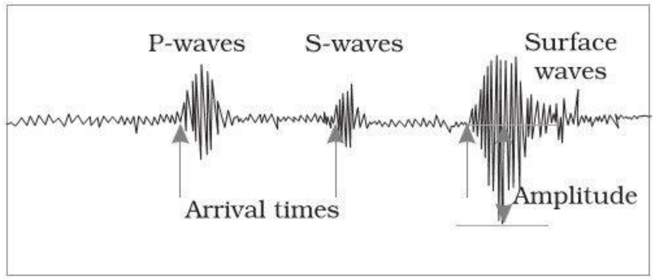
- Under intense pressure, the rock layer, at certain point, overcomes the friction offered by the overlying layer and undergoes an abrupt movement generating shockwaves.
- This causes a release of energy, and the energy waves travel in all directions.
- The point where the energy is released is called the **focus** of an earthquake, alternatively, it is called the **hypocentre.**
- The energy waves travelling in different directions reach the surface. The point on the surface, nearest to the focus, is called **epicentre.** It is the first one to experience the waves. It is a point directly above the focus.

Earthquake Waves

- All natural earthquakes take place in the lithosphere (depth up to 200 km from the surface of the earth).
- An instrument called 'seismograph' records the waves reaching the surface.
- Earthquake waves are basically of two types — **body waves** and **surface waves.**
- Body waves are generated due to the **release of energy at the focus** and move in all directions travelling through the body of the earth. Hence, the name body waves.
- **The body waves interact with the surface rocks and generate new set of waves called surface waves.** These waves move along the surface.
- The velocity of waves changes as they travel through materials with different elasticity (stiffness) (Generally density with few exceptions). **The more elastic the material is, the higher is the velocity.** Their direction also changes as they reflect or refract when coming across materials with different densities.
- There are two types of body waves. They are called **P and S-waves**.

Behavior of Earthquake Waves

- The earthquake waves are measured with the help of a seismograph and are of three types—



1. ***the 'P' waves or primary waves (longitudinal nature),***
2. ***secondary waves or 'S' waves (transverse in nature) while the***
3. ***surface waves are long or 'L' waves.***

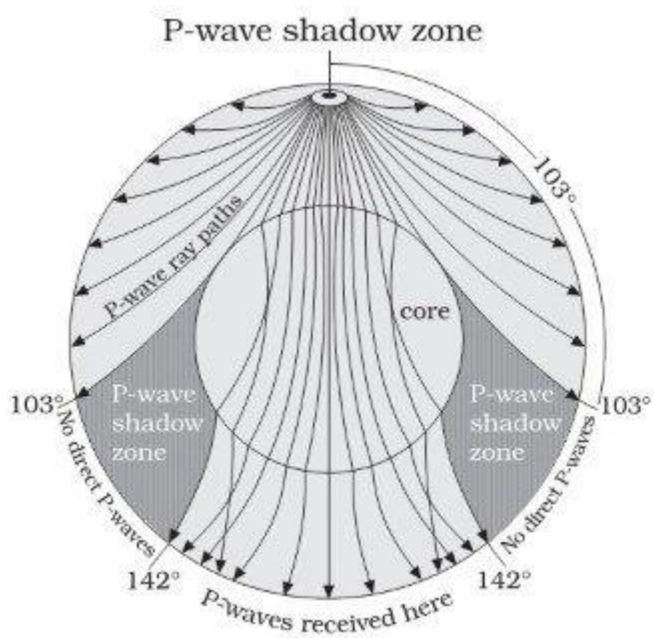
- The **velocity and direction** of the earthquake waves undergo changes when the medium through which they are travelling changes.
- When an earthquake or underground nuclear test sends shock waves through the Earth, the cooler areas, which generally are rigid, transmit these waves at a higher velocity than the hotter areas.

Primary Waves (P waves)

- Also called as the longitudinal or **compressional waves**.
- Particles of the medium vibrate along the direction of propagation of the wave.
- **P-waves move faster and are the first to arrive at the surface.**
- These waves are of **high frequency.**
- They can travel in **all mediums.**
- Velocity of P waves in **Solids > Liquids > Gases**
- Their velocity depends on **shear strength or elasticity** of the material.

  [We usually say that the speed of sound waves depends on density. But there are few exceptions. For example: Mercury (liquid metal) has density greater than Iron but speed of sound in mercury is lesser compared to that in iron. This is because the shear strength of mercury is very low (this is why mercury is liquid) compared to that of iron.]

- The shadow zone for 'P' waves is an area that corresponds to an angle between 103^0 and 142^0



- This gives clues about Solid inner core

Secondary Waves (S waves)

- Also called as transverse or **distortional waves**.
- Analogous to **water ripples** or light waves.
- S-waves arrive at the surface with some time lag.
- A secondary wave **cannot pass through liquids or gases.**
- These waves are of high frequency waves.
- Travel at varying velocities (**proportional to shear strength**) through the solid part of the Earth's crust, mantle.
- The **shadow zone** of 'S' waves extends **almost halfway** around the globe from the earthquake's focus.
- The shadow zone for ‘S’ waves is an area that corresponds to an angle between 103^0 and 180^0
- This observation led to the discovery of liquid outer core. Since S waves cannot travel through liquid, they do not pass through the liquid outer core.

Surface Waves (L waves)

- Also called as **long period waves.**
- They are **low frequency, long wavelength**, and **transverse vibration**.
- Generally affect the surface of the Earth only and die out at smaller depth.
- Develop in the immediate neighborhood of the epicenter.
- They cause displacement of rocks, and hence, the collapse of structures occurs.
- These waves are responsible for **most the destructive force** of earthquake.
- Recoded last on the seismograph.

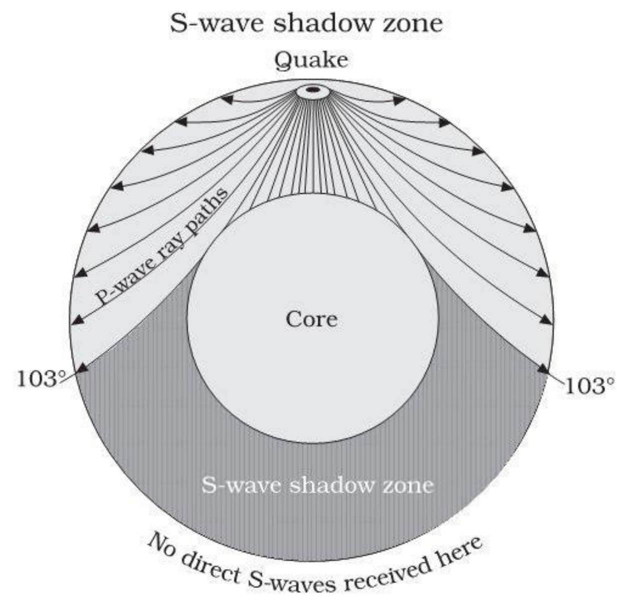
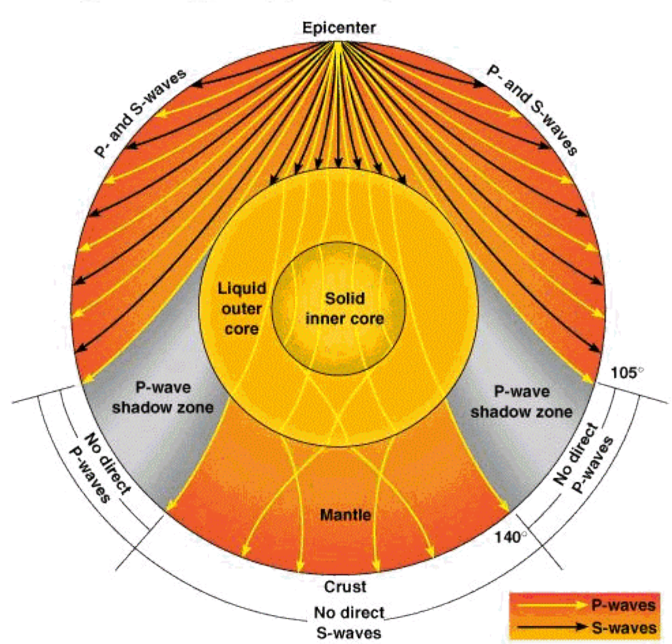


Figure 3.2 (a) and (b) : Earthquake Shadow Zones

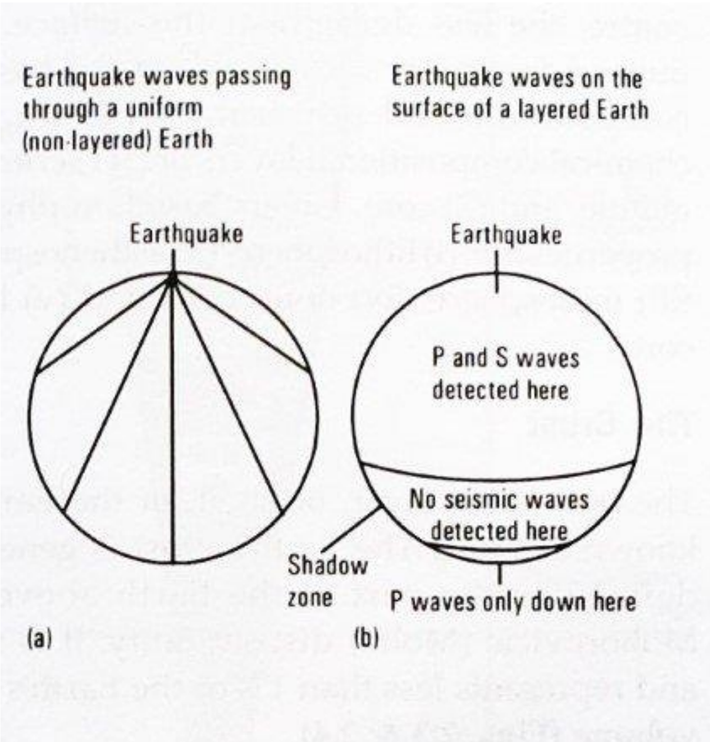


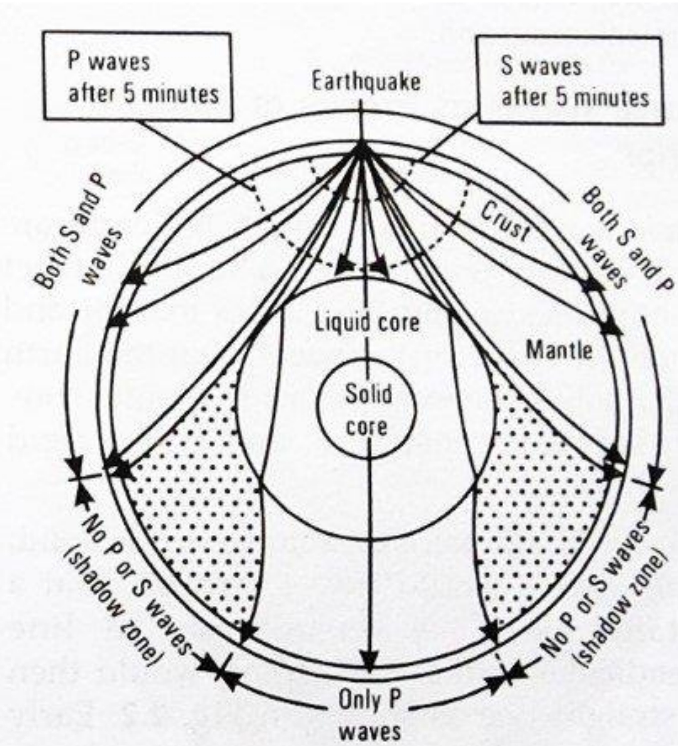
Propagation of Earthquake Waves

- Different types of earthquake waves travel in different manners. As they move or propagate, they cause vibration in the body of the rocks through which they pass.

- P-waves vibrate parallel to the direction of the wave. This exerts pressure on the material in the direction of the propagation.
- As a result, it creates density differences in the material leading to stretching and squeezing of the material.
- Other two waves vibrate perpendicular to the direction of propagation.
- The direction of vibrations of S-waves is perpendicular to the wave direction in the vertical plane. Hence, they create **troughs and crests** in the material through which they pass.

Emergence of Shadow Zone





- Earthquake waves get recorded in seismographs located at far off locations.
- However, there exist some specific areas where the waves are not reported. Such a zone is called the **'shadow zone'.**
- The study of different events reveals that for each earthquake, there exists an altogether different shadow zone. Figure 3.2 (a) and (b) show the shadow zones of P and S-waves.
- It was observed that seismographs located at any distance within 105 ° from the epicenter, recorded the arrival of both P and S-waves.
- However, the seismographs located beyond 145 ° from epicenter, record the arrival of P-waves, but not that of S-waves.
- Thus, a zone between **105 ° and 145 °** from epicenter was identified as the shadow zone for **both** the types of waves.

The entire zone beyond 105 ° does not receive S-waves.

- The shadow zone of S-wave is much larger than that of the P-waves. The shadow zone of P-waves appears as a band around the earth between 105 ° and 145 ° away from the epicenter.
- The shadow zone of S-waves is not only larger in extent but it is also a little over 40 per cent of the earth surface.

But how these properties of 'P' and 'S' waves help in determining the earth's interior?

- Reflection causes waves to rebound whereas refraction makes waves move in different directions.
- The variations in the direction of waves are inferred with the help of their record on seismograph.

- Change in densities greatly varies the wave velocity.
- By observing the changes in velocity, the density of the earth as a whole can be estimated.
- By the observing the changes in direction of the waves (emergence of shadow zones), different layers can be identified.

***Not important for exam**. But if you are a science enthusiast and if you want to know more…*

Why does sound wave travel faster in a denser medium whereas light travels slower?

Sound is a mechanical wave and travels by compression and rarefaction of the medium.
Its velocity in an elastic medium is proportional to the square root of Tension in the medium.
A higher density leads to more elasticity in the medium and hence the ease by which compression and rarefaction can take place. This way the velocity of sound increases by increase in density.
Light on the other hand is a transverse electromagnetic wave.
It does not depend on the elastic property of the medium in which it travels.
Its velocity in a medium is determined by the electromagnetic (e.g. dielectric) properties of the medium.
Effective path length on the other hand is increased by an increase in the density and hence it leads to higher refractive index and lower velocity.

Why S-waves cannot travel through liquids?

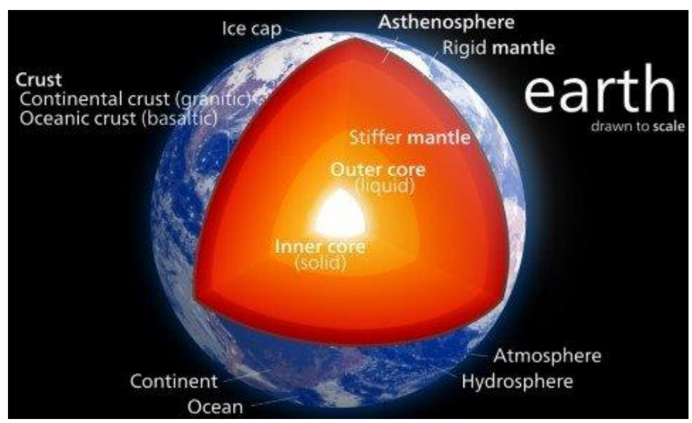
S-waves are shear waves, which move particles perpendicularly to their direction of propagation.
They can propagate through solid rocks because these rocks have enough **shear strength**.
The shear strength is one of the forces that hold the rock together, and prevent it from falling into pieces.
Liquids do not have the same shear strength: that is why, if you take a glass of water and suddenly remove the glass, the water will not keep its glass shape and will just flow away.
In fact, it is just a matter of rigidity: S-waves need a medium rigid enough to propagate. Hence, S-waves do not propagate through liquids.

Earth's Layers

- Earth's layers are identified by studying various direct and indirect sources [we studied this in previous post].
- The structure of the earth's interior is made up of several **concentric layers**.
- Broadly three layers can be identified—**crust, mantle** and the **core**.

Earth's Layers based on chemical properties

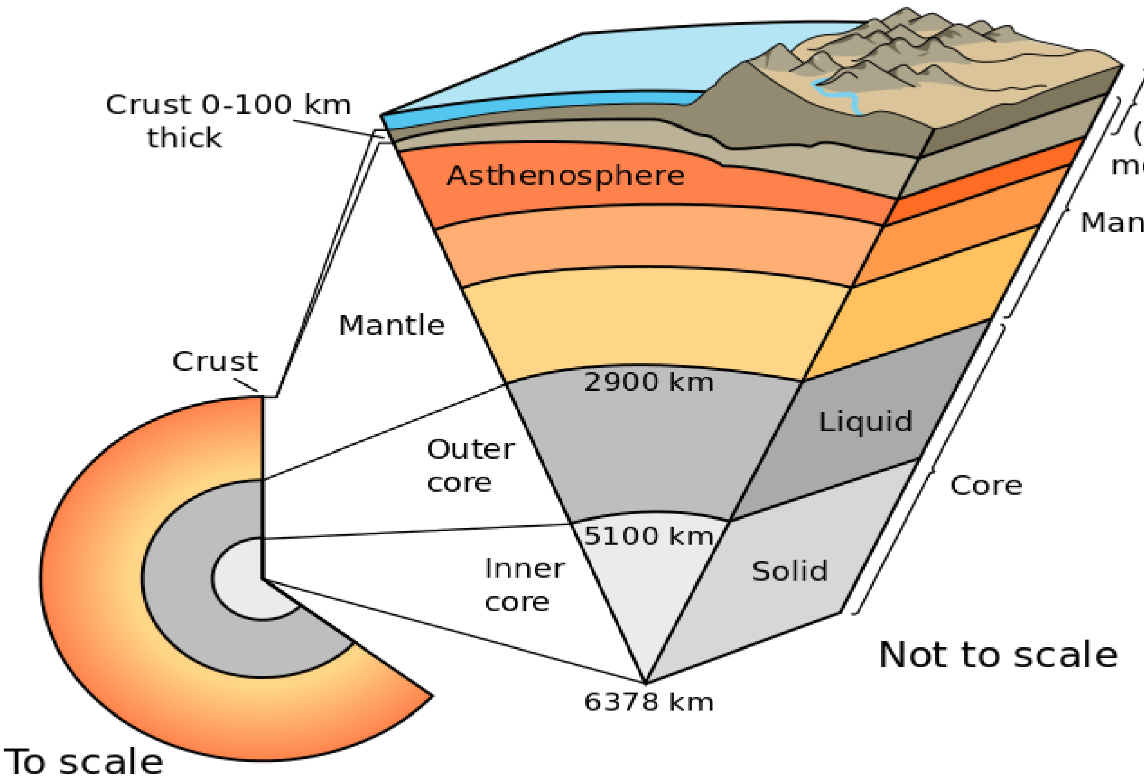
(1) crust,
(2) mantle, and
(3) core.

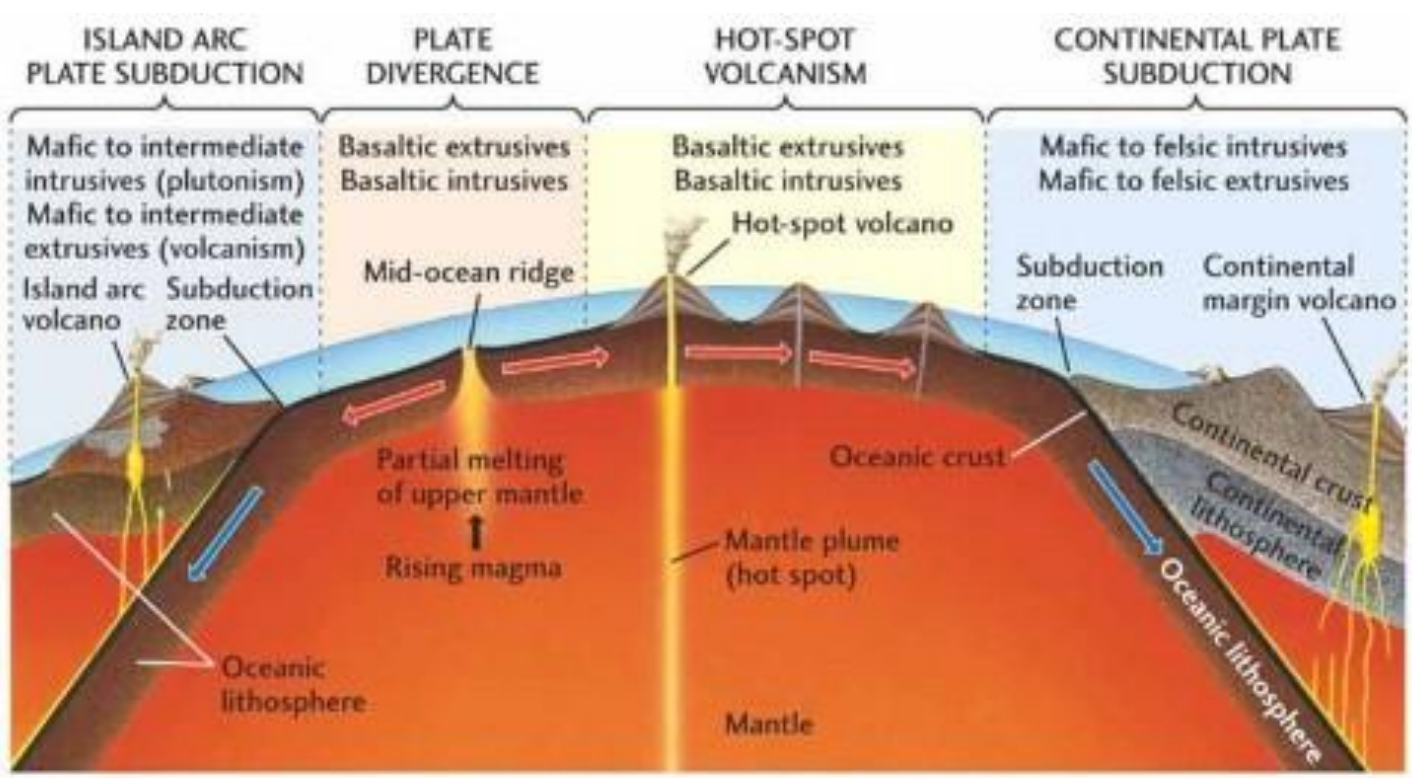


Earth's Layers - The Crust

- Crust is the outer thin layer with a total thickness normally between **30-50 km**.
- The thickness of the crust varies under the oceanic and continental areas.
- Oceanic crust is **thinner (5-30 km thick)** as compared to the continental crust **(50-70 km thick).**
- The continental crust is thicker in the areas of major mountain systems. It is as much as **70 -100 km** thick in the Himalayan region.

- It forms **0.5-1.0 per cent** of the earth's volume.





- **Mohorovicic (Moho) discontinuity** forms the boundary between crust and asthenosphere [asthenosphere is a part of mantle].

- The outer covering of the crust is of sedimentary material (granitic rocks) 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'**).

Earth's Layers - Mantle

- The mantle extends from **Moho's discontinuity** (35 km) to a depth of **2,900 km (**Moho-Discontinuity to the outer core**).**
- The crust and the uppermost part of the mantle are called **lithosphere.** Its thickness ranges from 10-200 km.
- The lower mantle extends beyond the asthenosphere. It is in solid state.
- The density of mantle varies between 2.9 and 3.3.
- The density ranges from 3.3 to 5.7 in the lower part.
- It is composed of solid rock and magma.
- It forms **83 per cent** of the earth's volume.
- The outer layer of the mantle is partly **simatic** while the inner layer is composed of wholly **simatic ultra-basic rocks**.

Earth's Layers - Asthenosphere

- The **upper portion of the mantle** is called **asthenosphere.**
- The word astheno means weak.
- It is considered to be extending up to **400 km.**
- It is the **main source of magma** that finds its way to the surface during volcanic eruptions. It has a density higher than the crust's.

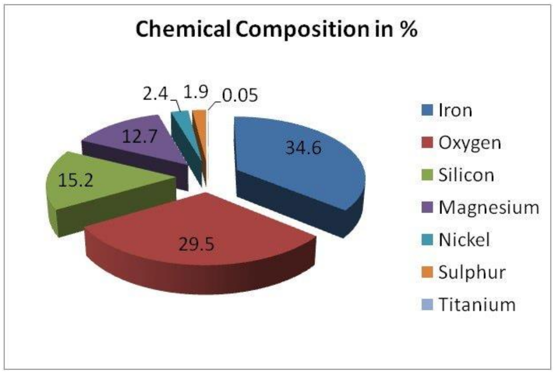
Earth's Layers - Core

- Lies between **2900 km and 6400 km** below the earth's surface.
- Accounts for **16 per cent** of the earth's volume.
- Core has the heaviest mineral materials of highest density.
- It is composed of **nickel and iron [nife].**
- The outer core is **liquid** while the inner core is **solid**.
- A zone of mixed heavy metals + silicates separates the core from outer layers.

Earth's Layers - Seismic Discontinuities

- **Mohorovicic Discontinuity** (Moho) - separates the crust from the mantle, its average depth being about 35 km.
- A soft **asthenosphere** (highly viscous, mechanically weak and ductile). It's a part of mantle.
- **Gutenberg Discontinuity** - lies between the **mantle and the outer core**. Below 2900 km from earth's surface.

Earth's Chemical Composition

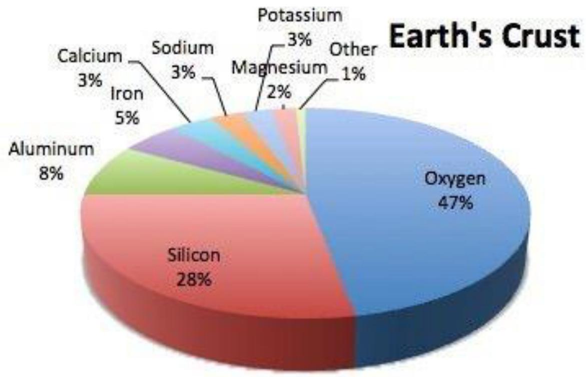


Composition of Earth's Crust

Table 5.1 : The Major Elements of the Earth's Crust

Sl. No.	*Elements*	*By Weight(%)*
1.	Oxygen	46.60
2.	Silicon	27.72
3.	Aluminium	8.13
4.	Iron	5.00
5.	Calcium	3.63
6.	Sodium	2.83
7.	Potassium	2.59
8.	Magnesium	2.09
9.	Others	1.41

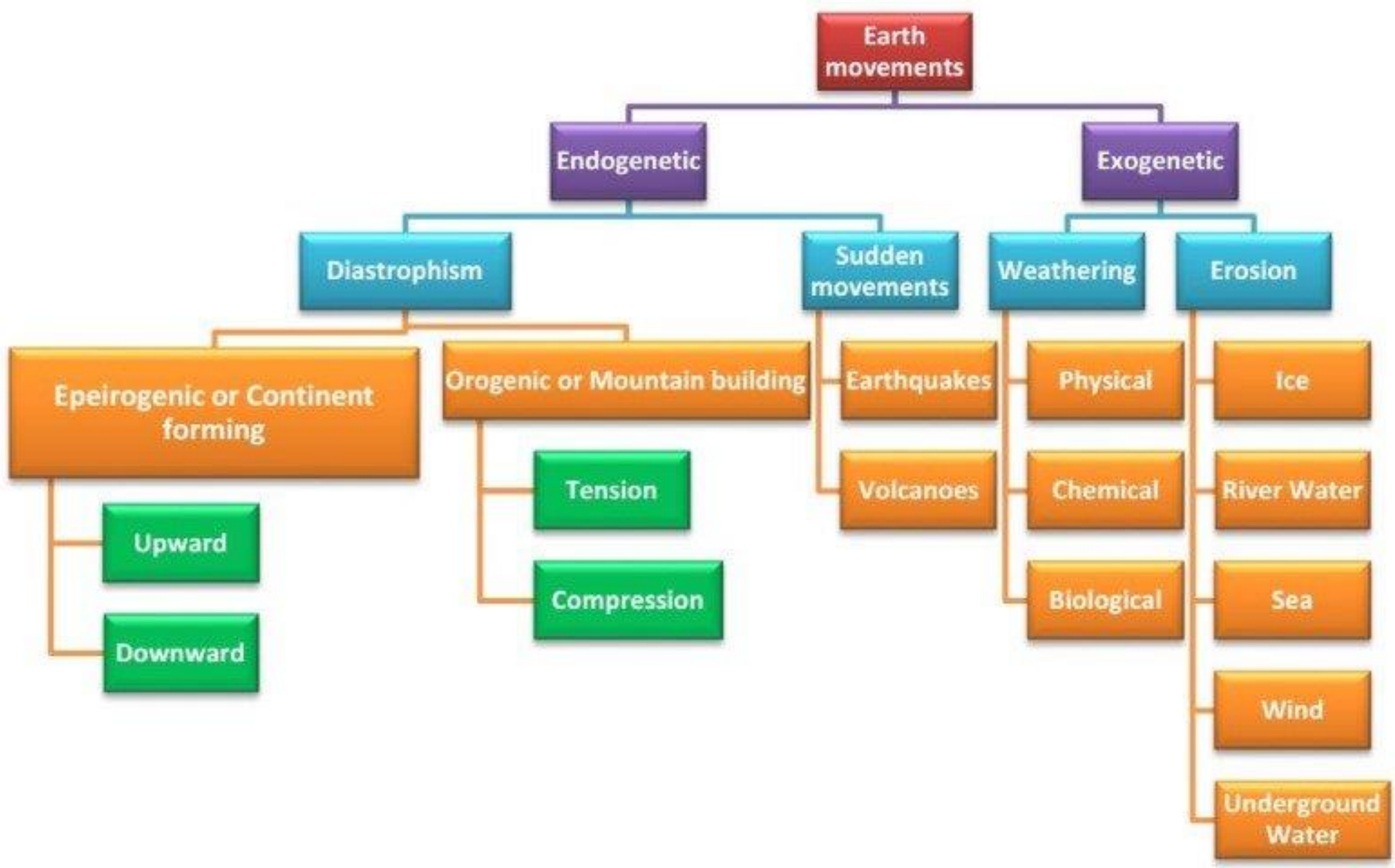
Earth Movements



- Our earth is undergoing deformations imperceptibly [so slight, gradual, or subtle as not to be perceived] but continuously.
- These deformations are caused by the movements generated by various factors like

1. **The heat generated by the radioactive elements in earth's interior.**
2. **Movement of the crustal plates due to tectogenesis.**
3. **Forces generated by rotation of the earth.**
4. **Climatic factors like winds, precipitation, pressure belts etc.**

- **Isostacy** ==> According to this concepts, blocks of the earth's crust, because of variations in density would rise to different levels and appear on the surface as mountains, plateau, plains or ocean basins
- **Tectonic** ==> relating to the structure of the earth's crust and the large-scale processes which take place within it.



Geomorphic processes

- Geomorphic == relating to the form of the landscape and other natural features of the earth's surface.
- The endogenic and exogenic forces causing physical and chemical changes on earth surface are known as geomorphic processes.
- **Diastrophism** and **volcanism** are endogenic geomorphic processes.
- **Weathering, mass wasting, erosion and deposition** are exogenic geomorphic processes.

- Geomorphic agent == mobile medium (like running water, moving ice masses, wind, waves and currents etc.) which removes, transports and deposits earth materials.

Endogenetic Movements

- The interaction of matter and temperature generates these forces or movements inside the earth's crust. The earth movements are mainly of two types: **diastrophism** and the **sudden movements**.
- 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. This energy due to geothermal gradients and heat flow from within induces diastrophism and volcanism in the lithosphere.

Diastrophism

- Diastrophism is the general term applied to **slow bending, folding, warping and fracturing**.
- **Wrap** == make or become bent or twisted out of shape, typically from the action of heat or damp; make abnormal; distort.
- All processes that move, elevate or build up portions of the earth's crust come under diastrophism. They include:

1. **orogenic processes** involving mountain building through severe folding and affecting long and narrow belts of the earth's crust;
2. **epeirogenic processes** involving uplift or warping of **large parts** of the earth's crust;
3. **earthquakes** involving local relatively minor movements;
4. **plate tectonics** involving horizontal movements of crustal plates.

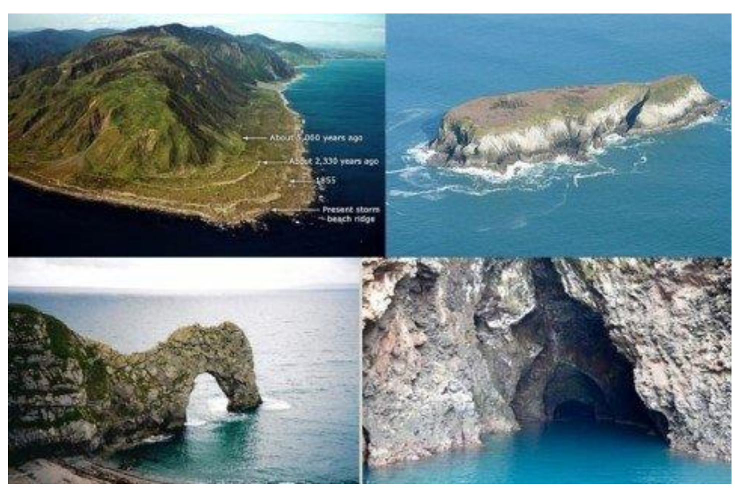
- In the process of orogeny, the crust is severely deformed into folds. Due to epeirogeny, there may be simple deformation. **Orogeny is a mountain building process whereas epeirogeny is continental building process.**
- Through the processes of orogeny, epeirogeny, earthquakes and plate tectonics, there can be faulting and fracturing of the crust. All these processes cause pressure, volume and temperature (PVT) changes which in turn induce metamorphism of rocks.

Epeirogenic or continent forming movements

- In geology, Epeirogenic movement refers to upheavals or depressions of land exhibiting **long wavelengths** [**undulations**] and little folding**.**
- The broad central parts of continents are called **cratons**, and are subject to epeirogeny.
- The movement is caused by a set of forces acting along an Earth radius, such as those contributing to **Isostacy** and **Faulting** in the lithosphere
- Epeirogenic or continent forming movements act **along the radius of the earth;** therefore, they are also called **radial movements**. Their direction may be **towards** **(subsidence)** or **away** **(uplift)** from the center. The results of such movements may be clearly defined in the relief.

Uplift

- Raised beaches, elevated wave-cut terraces, sea caves and fossiliferous beds above sea level are evidences of uplift.



- Raised beaches, some of them elevated as much as 15 m to 30 m above the present sea level, occur at several places along the Kathiawar, Nellore, and Thirunelveli coasts.
- Several places which were on the sea some centuries ago are now a few miles inland. For example, **Coringa near the mouth of the Godavari, Kaveripattinam in the Kaveri delta** and **Korkai on the coast of Thirunelveli**, were all flourishing sea ports about 1,000 to 2,000 years ago.

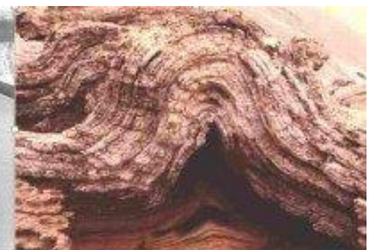
Subsidence

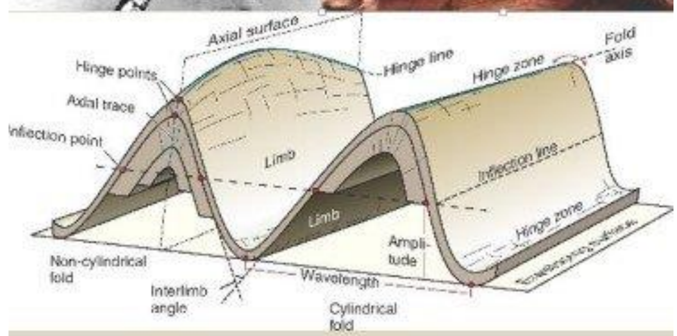
- Submerged forests and valleys as well as buildings are evidences of subsidence.
- In 1819, a part of the **Rann of Kachchh** was submerged as a result of an earthquake.
- Presence of **peat and lignite** beds below the sea level in **Thirunelveli** and the **Sunderbans** is an example of subsidence.
- 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 mud about 4 m below low water mark. A similar submerged forest has also been noticed on the Thirunelveli 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 (Madras) is submerged in the sea.

Orogenic or the mountain-forming movements

- Orogenic or the mountain-forming movements **act tangentially to the earth surface,** as in plate tectonics.
- **Tensions** 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). In the landforms so produced, the structurally identifiable units are difficult to recognise.
- In general, diastrophic forces which have uplifted lands have predominated over forces which have lowered them.





Sudden Movements

- These movements cause considerable deformation over a short span of time, and may be of two types.

Earthquake

- It occurs when the **surplus accumulated stress** in rocks in the earth's interior is **relieved through the weak zones** over the earth's surface in form of **kinetic energy** of wave motion causing vibrations (at times devastating) on the earth's surface. Such movements may result in uplift 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 upto 3 metres in some

areas while some areas in Japan (1891) subsided by 6 metres after an earthquake.

- Earthquakes may cause change in contours, change in river courses, 'tsunamis' (seismic waves created in sea by an earthquake, as they are called in Japan) which may cause shoreline changes, spectacular glacial surges (as in Alaska), landslides, soil creeps, mass wasting etc.

Volcanoes

- Volcanism includes the movement of molten rock (magma) onto or toward the earth's surface and also formation of many intrusive and extrusive volcanic forms.
- 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. Depending on chemical composition and viscosity of the lava, a volcano may take various forms.
- **Pyroclastic** ==> adjective of or denoting rock fragments or ash erupted by a volcano, especially as a hot, dense, destructive flow.

Earth Movements - Exogenetic Forces

- Exogenic (Exogenetic) processes are a direct result of stress induced in earth materials due to various forces that come into existence due to sun's heat.
- Force applied per unit area is called stress. Stress is produced in a solid by pushing or pulling.
- Forces acting along the faces of earth materials are **shear stresses** (separating forces). It is this stress that breaks rocks and other earth materials.
- Earth materials become subjected to **molecular stresses** caused due to temperature changes.
- Chemical processes normally lead to loosening of bonds between grains.
- Thus, the basic reason that leads to weathering, erosion and deposition is development of stresses in the body of the earth materials.
- Temperature and precipitation are the two important climatic elements that control various processes by inducing stress in earth materials.

Denudation

- All the exogenic geomorphic processes are covered under a general term, denudation.
- The word 'denude' means to strip off or to uncover.
- **Weathering, mass wasting/movements, erosion** and **transportation** are included in denudation.

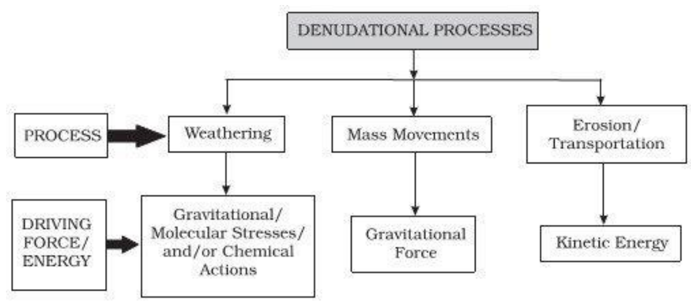


Figure 6.1 : Denudational processes and their driving forces

- Denudation mainly depends on rock type and its structure that includes folds, faults, orientation and inclination of beds, presence or absence of joints, bedding planes, hardness or softness of constituent minerals, chemical susceptibility of mineral constituents; the permeability or impermeability etc.
- 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**.

WEATHERING

- Weathering is defined as **mechanical disintegration** and **chemical decomposition** of rocks through the actions of various elements of weather and climate.
- As very little or no motion of materials takes place in weathering, it is an **in-situ or on-site process.**

- There are three major groups of weathering processes: **(i) chemical; (ii) physical or mechanical; (iii) biological weathering processes.**

Chemical Weathering Processes

- A group of weathering processes viz; solution, carbonation, hydration, oxidation and reduction act on the rocks to decompose, dissolve or reduce them to a fine state.
- Water and air (oxygen and carbon dioxide) along with heat speed up all chemical reactions.

Solution

- When something is dissolved in water or acids, the water or acid with dissolved contents is called solution.
- On coming in contact with water many solids disintegrate. Soluble rock forming minerals like nitrates, sulphates, and potassium etc. are affected by this process.
- So, these minerals are easily **leached** out without leaving any residue in rainy climates and accumulate in dry regions.

Carbonation

- Carbonation is the reaction of carbonate and bicarbonate with minerals.
- Carbon dioxide from the atmosphere and soil air is absorbed by water, to form **carbonic acid** that acts as a **weak acid** on various minerals.

Hydration

- Hydration is the chemical addition of water.
- Minerals take up water and expand; this expansion causes an increase in the volume of the material itself or rock.
- This process is reversible and long, continued repetition of this process causes fatigue in the rocks and may lead to their disintegration.
- The volume changes in minerals due to hydration will also help in physical weathering through **exfoliation** and **granular disintegration**.

Oxidation and Reduction

- In weathering, oxidation means a combination of a mineral with oxygen to form oxides (rusting in case of iron) or hydroxides. **Red soils** appear red due to the presence of iron oxides.
- Oxidation occurs where there is ready access to the atmosphere and water.
- The minerals most commonly involved in this process are iron, manganese, sulphur etc.
- When oxidized minerals are placed in an environment where oxygen is absent, reduction takes place.
- Such conditions exist usually below the water table, in areas of stagnant water and waterlogged ground.
- Red colour of iron upon reduction turns to greenish or bluish grey.

These weathering processes are interrelated. Hydration, carbonation and oxidation go hand in hand and hasten the weathering process.

Biological activity and weathering

- Biological weathering is removal of minerals and ions from the weathering environment and physical changes due to growth or movement of organisms.
- Burrowing and wedging by organisms like earthworms, rodents etc., help in exposing the new surfaces to chemical attack and assists in the penetration of moisture and air.
- Human beings by disturbing vegetation, ploughing and cultivating soils, also help in mixing and creating new contacts between air, water and minerals in the earth materials.
- Decaying plant and animal matter help in the production of humic, carbonic and other acids which enhance decay and solubility of some elements.

- Algae utilise mineral nutrients for growth and help in concentration of iron and manganese oxides.
- Plant roots exert a tremendous pressure on the earth materials mechanically breaking them apart.

Physical Weathering Processes

- Physical or mechanical weathering processes depend on some applied forces like (i) gravitational forces (ii) expansion forces due to temperature changes, crystal growth or animal activity; (iii) water pressures controlled by wetting and drying cycles.

Unloading and Expansion

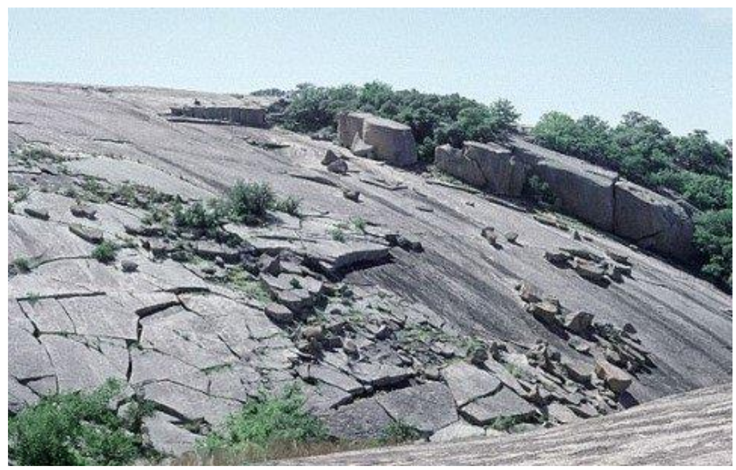
- Removal of overlying rock load because of continued erosion causes vertical pressure release with the result that the upper layers of the rock expand producing disintegration of rock masses.
- In areas of curved ground surface, arched fractures tend to produce massive sheets or exfoliation slabs of rock.

Granular Disintegration

- Rocks composed of coarse mineral grains commonly fall apart grain by grain or undergo granular disintegration.

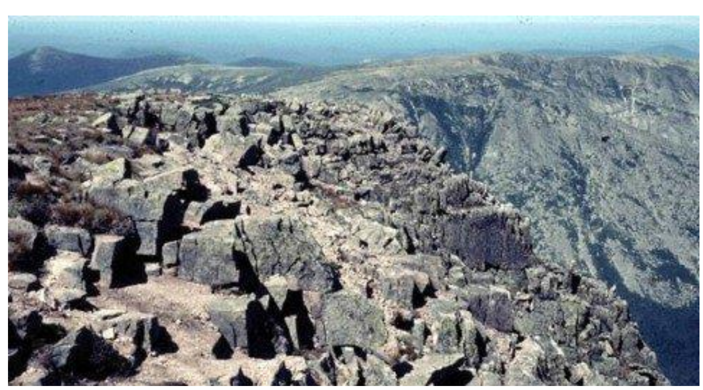
Exfoliation - Temperature Changes and Expansion

- With rise in temperature, every mineral expands and pushes against its neighbor and as temperature falls, a corresponding contraction takes place.
- Because of diurnal changes in the temperatures, this internal movement among the mineral grains takes place regularly.
- This process is most effective in dry climates and high elevations where diurnal temperature changes are drastic.
- The surface layers of the rocks tend to expand more than the rock at depth and this leads to the formation of stress within the rock resulting in heaving and fracturing parallel to the surface.
- Exfoliation results in smooth rounded surfaces in rocks.



Block Separation

- This type of disintegration takes place in rocks with numerous joints acquired by mountain-making pressures or by shrinkage due to cooling.
- This type of disintegration in rocks can be achieved by comparatively weaker forces.



Shattering

- A huge rock may undergo disintegration along weak zones to produce highly angular pieces with sharp corners and edges through the process of shattering.

Freezing, Thawing and Frost Wedging

- During the warm season, the water penetrates the pore spaces or fractures in rocks.
- During the cold season, the water freezes into ice and its volume expands as a result.
- This exerts tremendous pressure on rock walls to tear apart even where the rocks are massive.
- Frost weathering occurs due to growth of ice within pores and cracks of rocks during repeated cycles of freezing and melting.

Salt Weathering

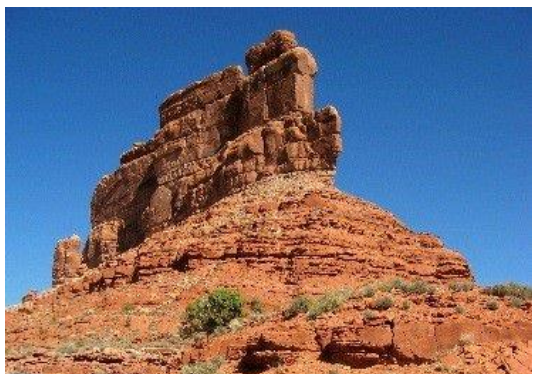
- Salts in rocks expand due to thermal action, hydration and crystallisation.
- Many salts like calcium, sodium, magnesium, potassium and barium have a tendency to expand.
- High temperature ranges in deserts favour such salt expansion.
- Salt crystals in near-surface pores cause splitting of individual grains within rocks, which eventually fall off. This process of falling off of individual grains may result in granular disintegration or granular foliation.

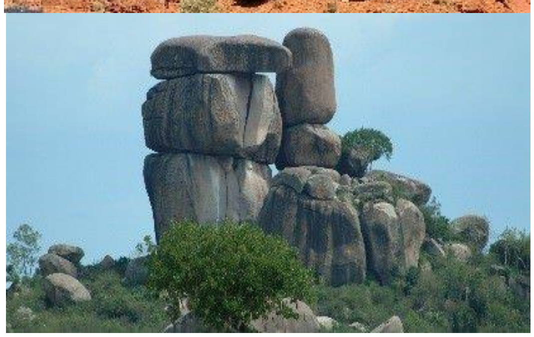
Mass Wasting

- Since gravity exerts its force on all matter, both bedrock and the products of weathering tend to slide, roll, flow or creep down all slopes in different types of earth and rock movements grouped under the term 'mass wasting'.

Effects of Weathering

- Weathering and erosion tend to level down the irregularities of landforms and create a **peneplane.**
- The strong wind erosion leaves behind whale-back shaped rocks in arid landscape. These are called **inselberg or ruware**.





- Sometimes a solid layer of chemical residue covers a soft rock. Sometimes, differential weathering of soft strata exposes the domelike hard rock masses, called tors. Tors are a common feature of South Indian landscape.

Weathering and Erosion

- Lead to simultaneous process of 'degradation' and 'aggradation'.
- Erosion is a mobile process while weathering is a static process [disintegrated material do not involve any motion except the falling down under force of gravity].

Significance of weathering

- Weathering is the first step in formation of soils.
- Weathering of rocks and deposits helps in the enrichment and concentrations of certain valuable ores of iron, manganese, aluminium, copper etc.
- Weathering helps in soil enrichment.
- Without weathering, the concentration of the same valuable material may not be sufficient and economically viable to exploit, process and refine. This is what is called enrichment.

Another important process in Exogenetic movements is erosion. We will study about erosion in Indian Geography.

Continental Drift Theory - Tectonics

- Tectonics == Large scale movement of lithospheric plates.

Introduction

- During WW II, scientists discovered that the ocean floor was not a flat surface but had some unique relief features like ridges, trenches, seamounts, shoals etc.
- The most important discoveries were ridges and trenches which gave insights into natural boundaries between various **lithospheric plates** (sometime called as **crustal plates** or **tectonic plates**)
- These important discoveries led to the theory of Plate Tectonics.

Plate Tectonics

- Plate tectonics is the large scale movement of lithospheric plates due to forces emanating from **earth's interior**.
- Prior to the theory of 'Plate Tectonics', there were other theories like '**Continental Drift Theory**' and **'See Floor Spreading Theory'** which tried to explain the large scale movements on earth's surface.
- In this post, we will study about '**Continental Drift Theory**'.

Important theories

1. **Polar wandering (Similar to Continental Drift Theory**)
2. **Continental Drift Theory (CDT)**
3. **Convectional Current Theory (CCT)**
4. **Sea Floor Spreading Theory (SFST)**
5. **Plate Tectonics (PT)**

- Polar wandering is the relative movement of the earth's crust and upper mantle with respect to the rotational poles of the earth.
- Continental drift refers to the movement of the **continents relative to each other**.
- Convectional current theory forms the basis of SFST and PT.
- Sea floor spreading describes the movement of **oceanic plates relative to one another**.
- Plate tectonics is simply the movement of **crustal plates relative to each other.**

Continental Drift Theory (Alfred Wegener, 1922)

- This theory was suggested by Alfred Wegener in 1920's.
- According to Wegener's **Continental Drift Theory**, there existed one big landmass which he called **Pangaea** which was covered by one big ocean called **Panthalassa**.
- A sea called **Tethys** divided the Pangaea into two huge landmasses: **Laurentia (Laurasia)** to the north and **Gondwanaland** to the south of Tethys.

The Continental Drift Theory

Piecing It All Together

PERMIAN
250 million years ago

The Atlantic and Indian oceans did not exist, and all the continents were configured into the universal landmass of Pangaea. The land was surrounded by one global ocean, called Panthalassa.

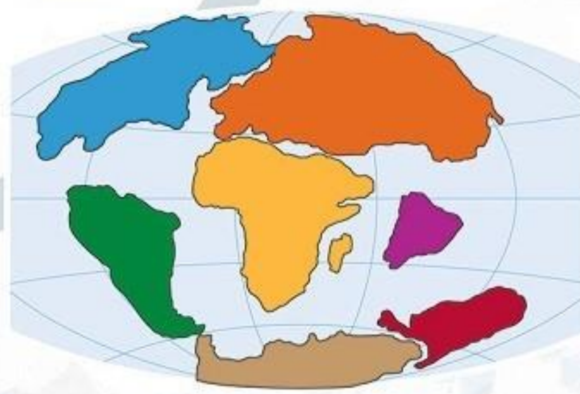
TRIASSIC
200 million years ago

The breakup of Pangaea began. Rifts formed, splitting West Gondwana from East Gondwana. India separated from Antarctica. Laurasia split from South America and Africa.

Two hundred and fifty million years ago, the land masses of Earth were clustered into one supercontinent called Pangaea. As millions of years passed, Pangaea broke apart, and large pieces of land slowly moved away to form the continents as we know them today.

JURASSIC
145 million years ago

Seafloor spreading further opened the central North Atlantic and Indian oceans. At the end of the period, a new rift split South America from Africa.



CRETACEOUS
65 million years ago

The movement continued. Madagascar drifted away from Africa, which continued its move north. The northward drift of India continued, and Australia split from Antarctica.

PRESENT DAY

New Zealand is split from Australia's east coast. The North and South Atlantic oceans are more open. Africa is slightly north, and India is joined with Asia.

Geologic time scale [Supereon>Eon>Era>Period>Epoch>Age]

Beginning of Pre-Chambrian Supereon

It lasted for nearly 4 billion years

- *Hadean Eon*
- *Archean Eon*
- *Proterozoic Eon*

End of Pre-Chambrian Supereon

The new Supereon is not given a name

It starts with

Phanerozoic Eon

- Paleozoic Era (570-225 m)
  - Cambrian Period (570 m)
  - Ordovician Period (500 m)
  - Silurian Period (440 m)
  - Devonian Period (395 m)
  - Carboniferous (345 m)
  - Permian Period (280 m) ➔ ***Pangea Intact***
- Mesozoic Era (225-70 m)
  - Triassic Period (225 m) ➔ ***Breakup of Pangea began***
  - Jurassic Period (195 m) ➔ ***All continents got separated except Europe and Asia.***
  - Cretaceous (136 m) ➔ ***All continents moving further apart except Eurasia. India reaches equator.***
- Cenozoic Era (70-0 m) ➔ ***Formation of Deccan traps begin. Late cretaceous and early Cenozoic era***
  - Paleogene Period
  - Neogene Period ➔ ***Tertiary period (40-50 million years ago) India collides with Asia.***

    Formation of Himalays.
  - Quaternary Period
  - Pleistocene epoch (1 m)
    - ✓ Stone Age
  - Halocene epoch (10,000 y)

- Drift started around **200 million years ago (Mesozoic Era)**, and the continents began to break up and drift away from one another.

Force for Continental Drift

The drift was in two directions-

1. equator wards due to the interaction of forces of **gravity, pole-fleeing force** and **buoyancy** (ship floats in water due to buoyant force offered by water), and
2. westwards due to **tidal currents** because of the earth's motion (earth rotates form west to east, so tidal currents act from east to west. **Watch video for better understanding**).

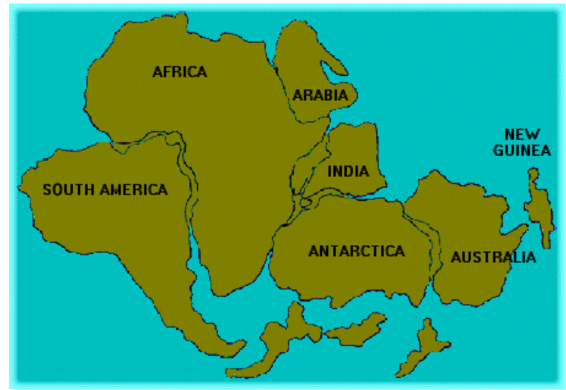
- Wegener suggested that **tidal force** also played a major role.
- The polar-fleeing force relates to the rotation of the earth. You are aware of the fact that the earth is not a perfect sphere; it has a bulge at the equator. This bulge is due to the rotation of the earth. [Greater Centrifugal force at the equator. Centrifugal force increases as we move from poles towards equator. This increase in centrifugal force has led to pole fleeing].
- Tidal force is due to the attraction of the moon and the sun that develops tides in oceanic waters.
- Wegener believed that these forces would become effective when applied over many million years.
- According to Wegener, the drift is **still continuing.**

Evidence in support of Continental Drift

Apparent Affinity of Physical Features

- South America and Africa seem to fit in with each other, especially, the bulge of Brazil fits into the Gulf of Guinea.
- Greenland seems to fit in well with Ellesmere and Baffin islands.
- The east coast of India, Madagascar and Africa seem to have been joined.

- North and South America on one side and Africa and Europe on the other fit along the mid-Atlantic ridge.



- The **Caledonian** and **Hercynian mountains** of Europe and the **Appalachians** of USA seem to be one continuous series.

Criticism

- Coastlines are a temporary feature and are liable to change.
- Several other combinations of fitting in of landforms could be attempted.
- Continental Drift Theory shifts India's position too much to the south, distorting its relation with the Mediterranean Sea and the Alps.
- The mountains do not always exhibit geological affinity.

Causes of Drift

- Gravity of the earth, buoyancy of the seas and the tidal currents were given as the main factors causing the drift, by Wegener.

Criticism

- This is illogical because for these factors to be able to cause a drift of such a magnitude, they will have to be millions of times stronger.

Polar wandering (Shifting of Poles)

- The poles drifted constantly.

Criticism

- Poles may have shifted, not necessarily the continents (don’t think deep).

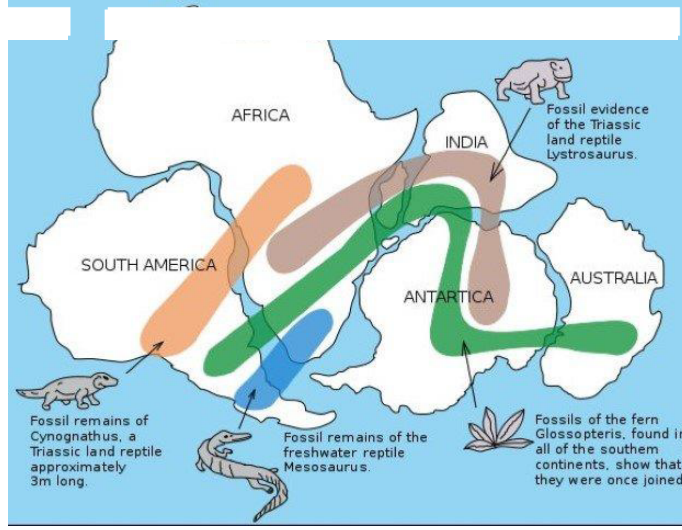
Botanical Evidence

- Presence of **glossopteris** vegetation in carboniferous rocks of India, Australia, South Africa, Falkland Islands (Overseas territory of UK), Antarctica, etc. can be explained on the basis of the fact that parts were linked in the past.

Criticism

- Such vegetation is also found in the northern parts like Afghanistan, Iran and Siberia.
- Similar vegetation found in unrelated parts of the world.

Rocks of Same Age Across the Oceans



- The belt of ancient rocks of 2,000 million years from Brazil coast matches with those from western Africa.

Criticism

- Rocks of same age and similar characteristics are found in other parts of the world too.

Tillite deposits

- It is the sedimentary rock formed out of deposits of glaciers. The Gondwana system of sediments from India is known to have its counter parts in six different landmasses of the Southern Hemisphere.
- At the base the system has thick Tillite indicating extensive and prolonged glaciation. Counter parts of this succession are found in **Africa, Falkland Island, Madagascar, Antarctica and Australia besides India.**
- Overall resemblance of the Gondwana type sediments clearly demonstrates that these landmasses had remarkably similar histories.
- The glacial Tillite provides unambiguous evidence of palaeoclimates and also of drifting of continents.

Placer Deposits

- Rich placer deposits of gold are found on the Ghana coast (West Africa) but the source (gold bearing veins) are in Brazil and it is obvious that the gold deposits of the Ghana are derived from the Brazil plateau when the two continents lay side by side.

Distribution of Fossils

- The observations that Lemurs occur in **India, Madagascar and Africa** led some to consider a contiguous landmass "**Lemuria**" linking these three landmasses.
- **Mesosaurus** was a small reptile adapted to shallow brackish water. The skeletons of these are found only in South Africa and Iraver formations of Brazil. The two localities presently are 4,800 km apart with an ocean in between them.

Drawbacks of Continental Drift Theory

- Wegener failed to explain why the drift began only in **Mesozoic era and not before**.
- The theory **doesn't take oceans into consideration**.
- Proofs heavily depend on **assumptions** and are very general in nature.
- Forces like buoyancy, tidal currents and gravity are too weak to be able to move continents.
- Modern theories (PT) accept the existence of Pangaea and related landmasses but give a very different explanation to the causes of drift.

In this post we will study about a very important concept called See Floor Spreading. Before jumping directly into the concept of See Floor Spreading, we must understand some basic concepts that form the corner stones for the concept of See Floor Spreading. These corner stones are **Convectional Current Theory** and **Paleomagnetism.**

Convectional Current Theory - Tectonics

- **Arthur Holmes** in 1930s discussed the possibility of convection currents in the mantle.
- These currents are generated due to radioactive elements causing **thermal differences** in mantle.

Mapping of the Ocean Floor

- Detailed research during World Wars revealed that the ocean floor is not just a vast plain but it is full of relief with mountain ranges, deep trenches etc..
- The **mid-oceanic ridges** were found to be most active in terms of volcanic eruptions.
- The dating of the rocks from the oceanic crust revealed the fact that the latter is much younger than the continental areas **(Rocks on ocean floor are much younger than those on the continents).**
- Rocks on either side of the crest of oceanic ridges and having equidistant locations from the crest were found to have **remarkable similarities** both in terms of their constituents and their age.

Distribution of Earthquakes and Volcanoes

- Volcanism and associated earthquakes at plate margins are a direct consequence of convection currents in the mantle.
- Dots in the central parts of the Atlantic Ocean and other oceans are almost parallel to the coastlines.
- In general, the foci of the earthquake in the areas of mid-oceanic ridges are at **shallow depths** whereas along the Alpine-Himalayan belt as well as the rim of the Pacific, the earthquakes are deep-seated ones **(deep focus earthquakes are more destructive).**
- The map of volcanoes also shows a similar pattern. The **rim of the Pacific** is also called **rim of fire** due to the existence of active volcanoes in this area.

These observations (ocean floor and the distribution of earthquakes and volcanoes) led to the theory of **See Floor Spreading**.

Convectional Current Theory is the soul of See Floor Spreading theory.

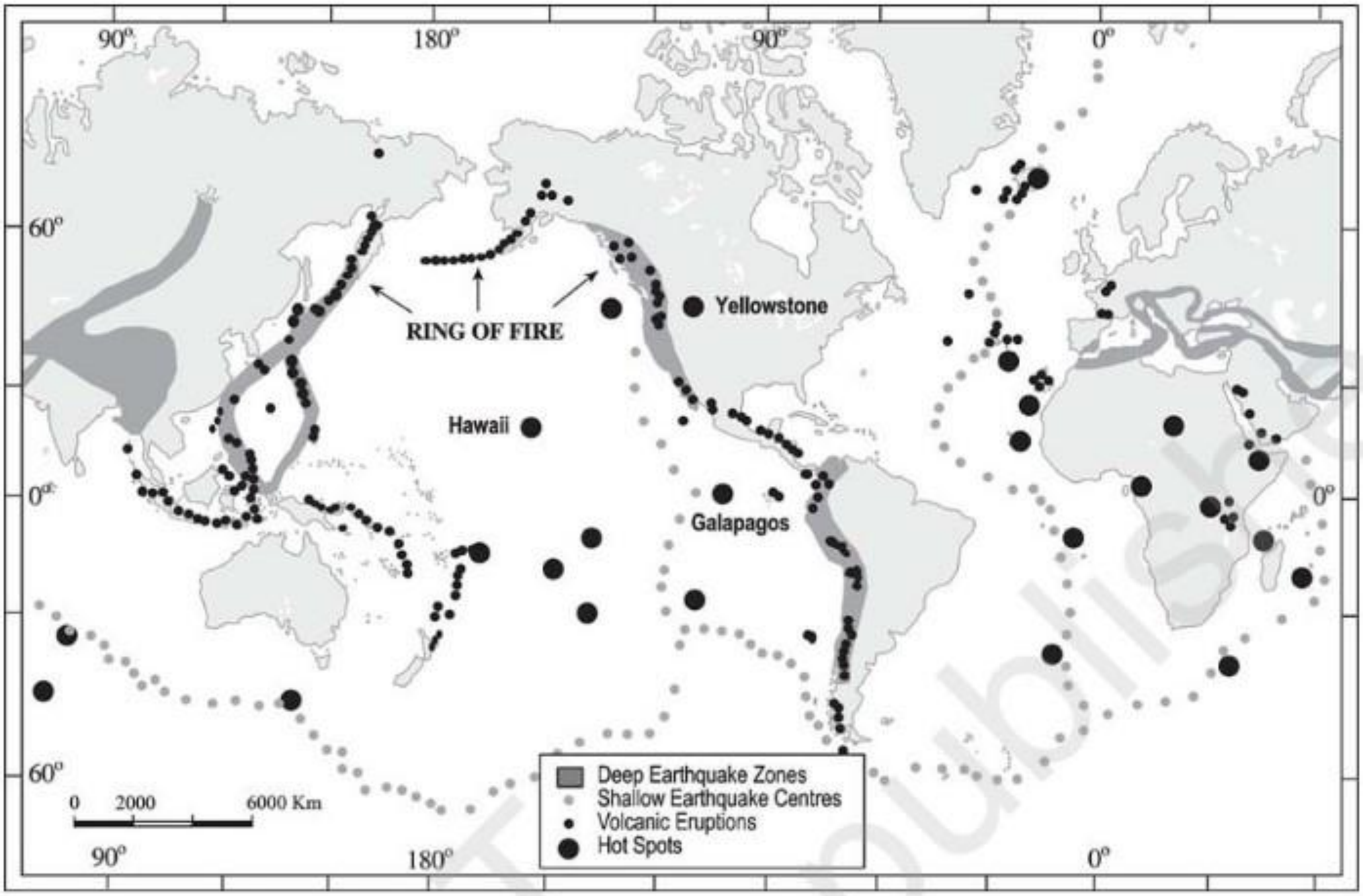
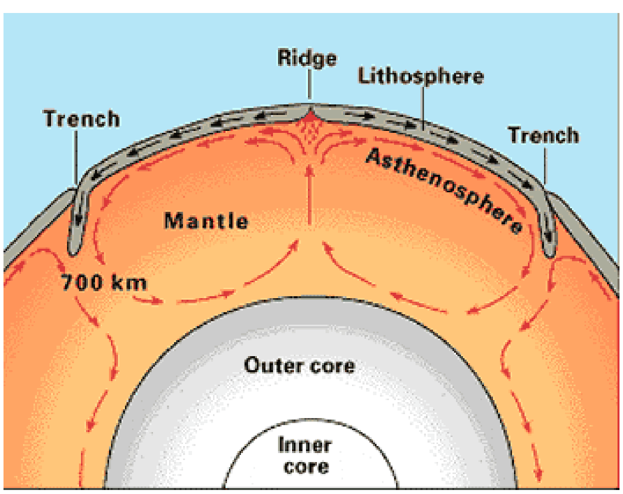


Figure 4. 2 : Distribution of earthquakes and volcanoes

Convectional Current Theory



- According to this theory, the intense heat generated by radioactive substances in the mantle (100-2900 km below the earth surface) seeks a path to escape, and gives rise to the formation of convention currents in the mantle.
- Wherever **rising limbs** of these currents meet, **oceanic** ridges are formed on the sea floor and wherever the **failing limbs** meet, **trenches** are formed.

Paleomagnetism

- It is the study of the record of the Earth's magnetic field in rocks, sediment etc..

  Why do we need to study this concept?

- Paleomagnetic rocks on either side of the submarine ridges provide the **most important evidence** to the concept of Sea Floor Spreading (next post).

  Paleo == Rocks; **Paleomagnetism == magnetism in rocks**.

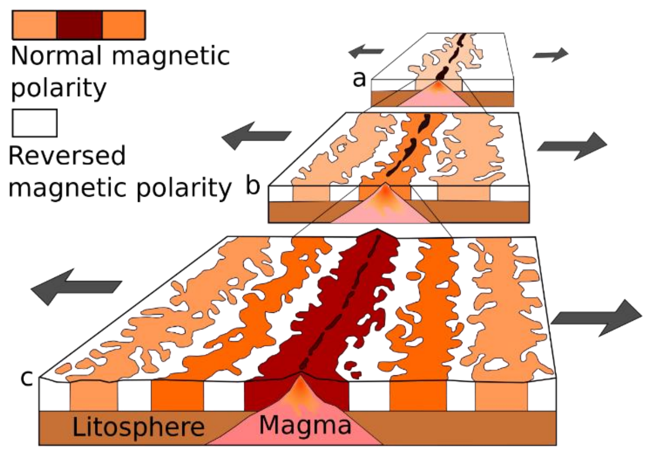
- Certain minerals in rocks lock-in a record of the **direction and intensity of the magnetic** field when they form.
- This record provides information on the **past behavior of Earth's magnetic field** and the past location of tectonic plates.

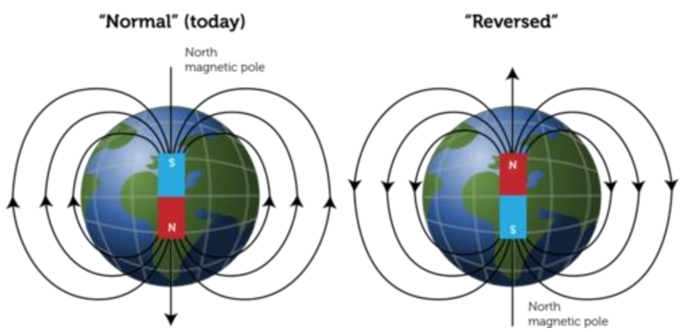
- Paleomagnetists led the **revival of the continental drift hypothesis** and **its transformation into plate tectonics.**
- Paleomagnetic studies of rocks and ocean sediment have demonstrated that the orientation of the earth's magnetic field has **frequently alternated** over geologic time.
- Periods of "normal" polarity (i.e., when the north-seeking end of the compass needle points toward the present north magnetic pole, as it does today) have alternated with periods of "reversed" polarity (when the north-seeking end of the compass needle points southward)[I have explained this in detail in the video].
- As today's magnetic field is close to the earth's rotational axis, continental drift could be tested by ascertaining the magnetic characteristics of ancient rocks.

Paleomagnetism: Strong evidence of See Floor Spreading and Plate Tectonics

- Some of the strongest evidence in support of the theory of see floor spreading and plate tectonics comes from studying the magnetic fields surrounding oceanic ridges.
- Rocks formed from this underwater volcanic activity were mainly **basalt,** which is **low silica, iron-rich, volcanic rock** that makes up most of the ocean floor.
- Basalt contains magnetic minerals and as the rock is solidifying, these minerals **align themselves in the direction of the magnetic field.**
- This basically locks in a record of which way the magnetic field was positioned at the time that part of the ocean floor was created.
- Paleomagnetists [scientists who study past magnetic fields], took a look at the ocean floor going out away from oceanic ridges (either side of the oceanic ridges), they found magnetic stripes that were flipped so that one stripe would be normal polarity and the next reversed.

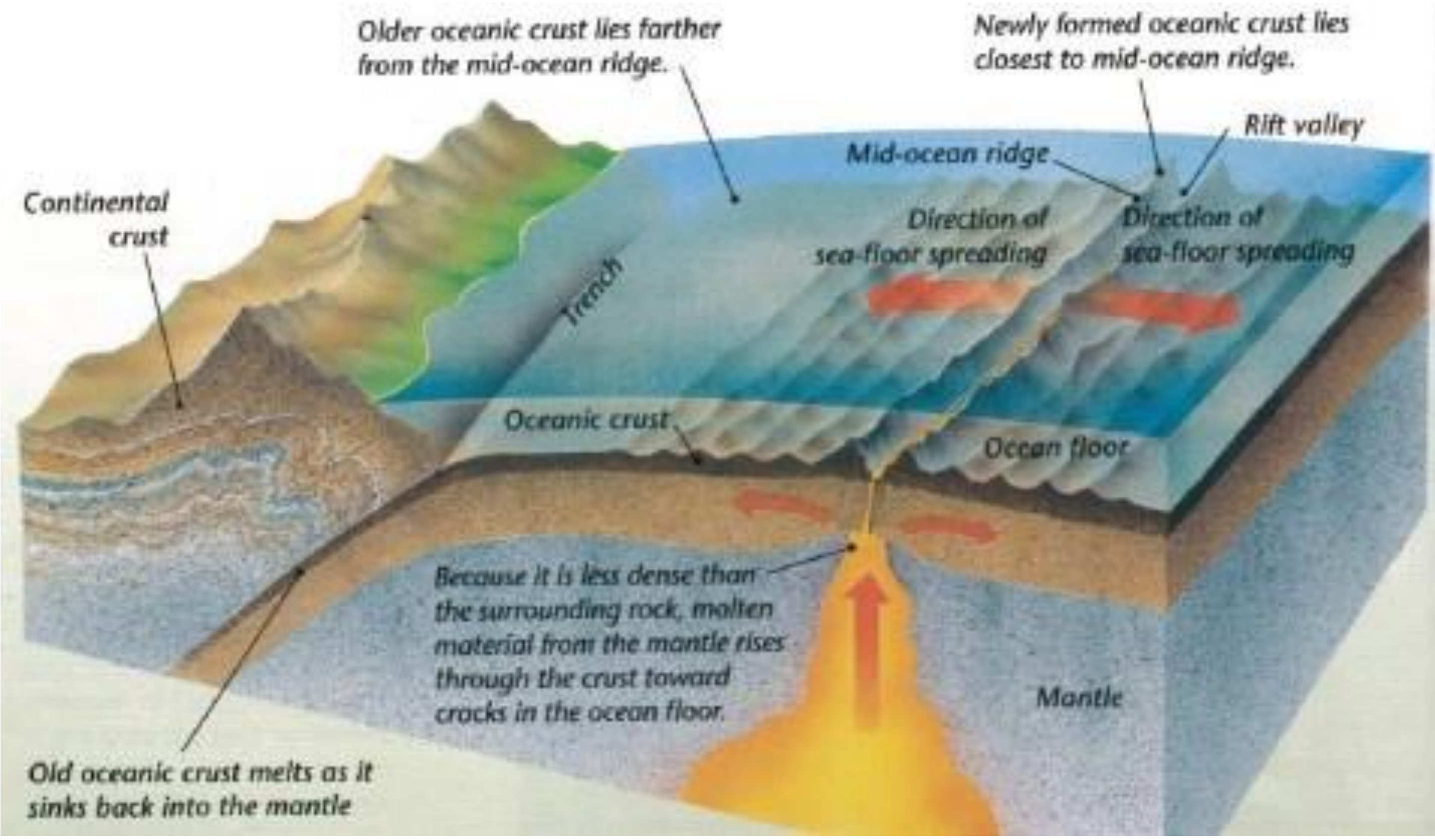
How could this be?





- These oceanic ridges were actually boundaries with tectonic plates pulling apart.
- This movement of the plates allowed the magma to rise up and harden into new rock.
- As the new rock was formed near the ridge, older rock, which formed millions of years ago when the magnetic field was reversed, got pushed farther away, resulting in this **magnetic striping.**
- Rising magma assumes the polarity of Earth's geomagnetic field before it solidifies into oceanic crust.
- At spreading centres, this crust is separated into parallel bands of rock by successive waves of emergent magma.
- When Earth's geomagnetic field undergoes a reversal, the change in polarity is recorded in the magma, which contributes to the **alternating pattern of magnetic striping on the seafloor.**

Concept of Sea Floor Spreading



- The idea that the seafloor itself moves (and carries the continents with it) as it expands from a central axis was proposed by **Harry Hess.**
- According to this theory, the intense heat generated by radioactive substances in the mantle (100-2900 km below the earth surface) seeks a path to escape, and gives rise to the formation of convention currents in the mantle.
- Wherever rising limbs of these currents meet, oceanic ridges are formed on the sea floor and wherever the failing limbs meet, trenches are formed.
- Seafloor spreading is a process that occurs at mid-ocean ridges, where new oceanic crust is formed through volcanic activity and then **gradually moves away from the ridge**.
- Seafloor spreading helps explain continental drift in the theory of plate tectonics. When oceanic plates diverge, tensional stress causes fractures to occur in the lithosphere.
- Basaltic magma rises up the fractures and cools on the ocean floor to form new sea floor.
- Older rocks will be found farther away from the spreading zone while younger rocks will be found nearer to the spreading zone.

Evidences

- The mapping of the ocean floor and Paleomagnetic studies of rocks from oceanic regions revealed the following facts :

1. **Volcanic eruptions are common all along the midoceanic ridges and they bring huge amounts of lava to the surface in this area.**
2. **The rocks equidistant on either sides of the crest of mid-oceanic ridges show remarkable similarities**
3. **Rocks closer to the mid-oceanic ridges are normal polarity and are the youngest.**
4. **The age of the rocks increases as one moves away from the crest.**
5. **The deep trenches have deep-seated earthquake occurrences while in the midoceanic ridge areas, the quake foci have shallow depths.**

- It was on the basis of the continental drift theory, theory of sea floor spreading, that the theory of **Plate Tectonics** was formulated—first outlined by Morgan in 1968.
- So, next post will be a detailed explanation on Plate Tectonics.

In this post we will study about one of the most important concept of geomorphology called Plate Tectonics. This is the third post in 'Tectonics' after 'Continental Drift Theory' and 'See Floor Spreading Theory'.

Plate Tectonics

- In 1967, McKenzie and Parker suggested the theory of plate tectonics. The theory was later outlined by Morgan in 1968.
- By then, the 'continental drift theory' was completely **discarded** with the emergence of 'convectional current theory' and 'see floor spreading theory'.
- Both 'convectional current theory' and 'see floor spreading' paved the way for the Theory of Plate Tectonics.

Theory

- According to the theory of plate tectonics, the earth's **lithosphere** is **broken** into **distinct plates** which are floating on a **ductile layer** called **asthenosphere** (upper mantle). Plates move horizontally over the **asthenosphere** as rigid units.
- The lithosphere includes the **crust** and **top mantle** with its thickness range varying between 5-100 km in oceanic parts and about 200 km in the continental areas.
- The oceanic plates contain mainly the **Simatic crust** and are relatively thinner, while the continental plates contain **Sialic material** and are relatively thicker.
- Lithospheric plates (sometimes called **crustal plates, tectonic plates**) vary from **minor plates** to **major plates**, **continental plates** (Arabian plate) to **oceanic plates** (Pacific plate), sometime a **combination** of both continental and oceanic plates (Indo-Australian plate).
- The movement of these crustal plates causes the formation of various landforms and is the principal cause of all earth movements.

Rates of Plate Movement

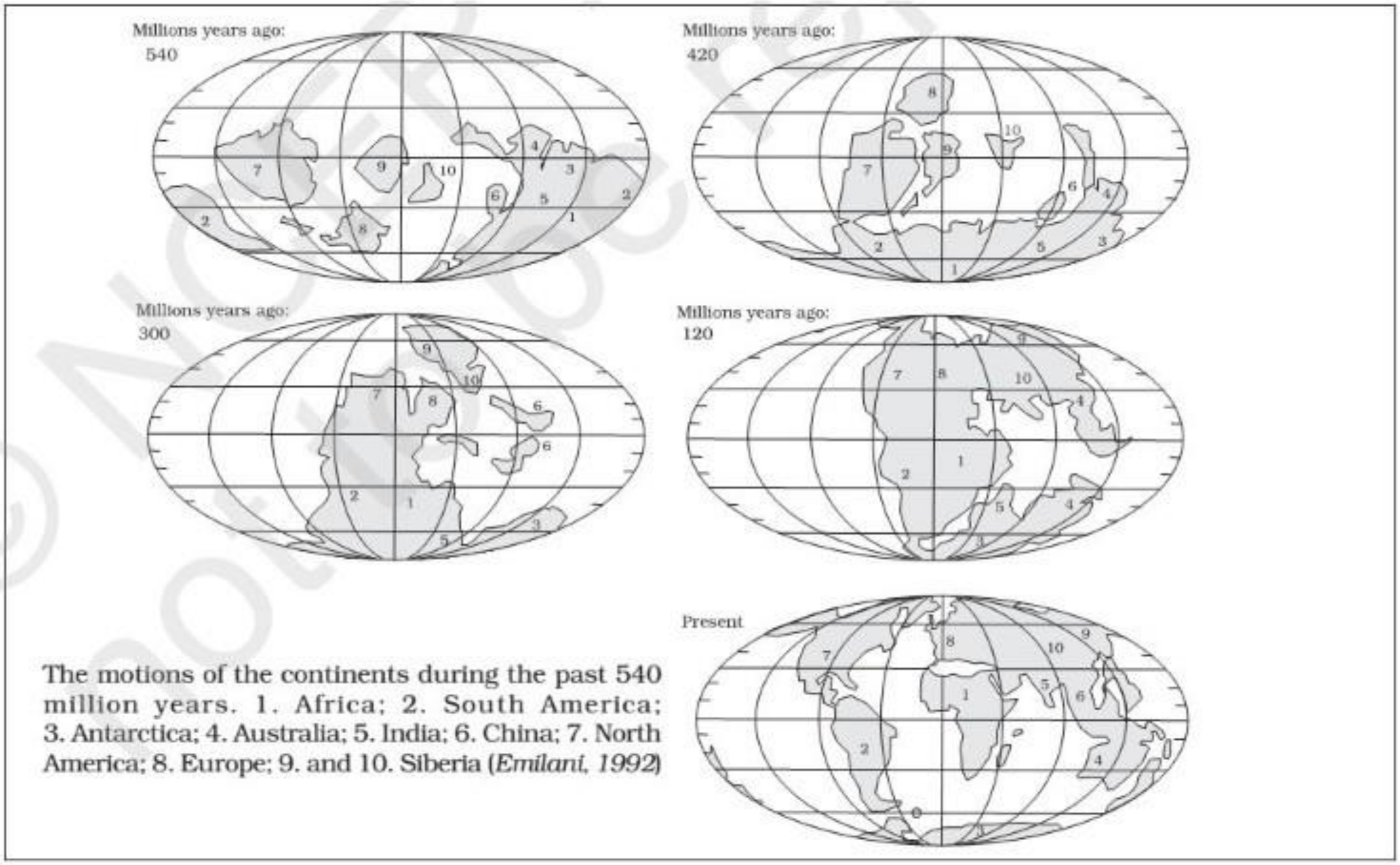
- The Arctic Ridge has the slowest rate (less than 2.5 cm/yr), and the East Pacific Rise in the South Pacific [about 3,400 km west of Chile], has the fastest rate (more than 15 cm/yr).
- Indian plate's movement during its journey from south to equator was one of the fastest plate movements.

Major tectonic plates

1. Antarctica and the surrounding oceanic plate
2. North American plate
3. South American plate
4. Pacific plate
5. India-Australia-New Zealand plate
6. Africa with the eastern Atlantic floor plate
7. Eurasia and the adjacent oceanic plate

Minor tectonic plates

1. Cocos plate: Between Central America and Pacific plate
2. Nazca plate: Between South America and Pacific plate
3. Arabian plate: Mostly the Saudi Arabian landmass
4. Philippine plate: Between the Asiatic and Pacific plate
5. Caroline plate: Between the Philippine and Indian plate (North of New Guinea)



The motions of the continents during the past 540 million years. 1. Africa; 2. South America; 3. Antarctica; 4. Australia; 5. India; 6. China; 7. North America; 8. Europe; 9. and 10. Siberia (*Emilani, 1992*)

Figure 4.4 : Position of continents through geological past

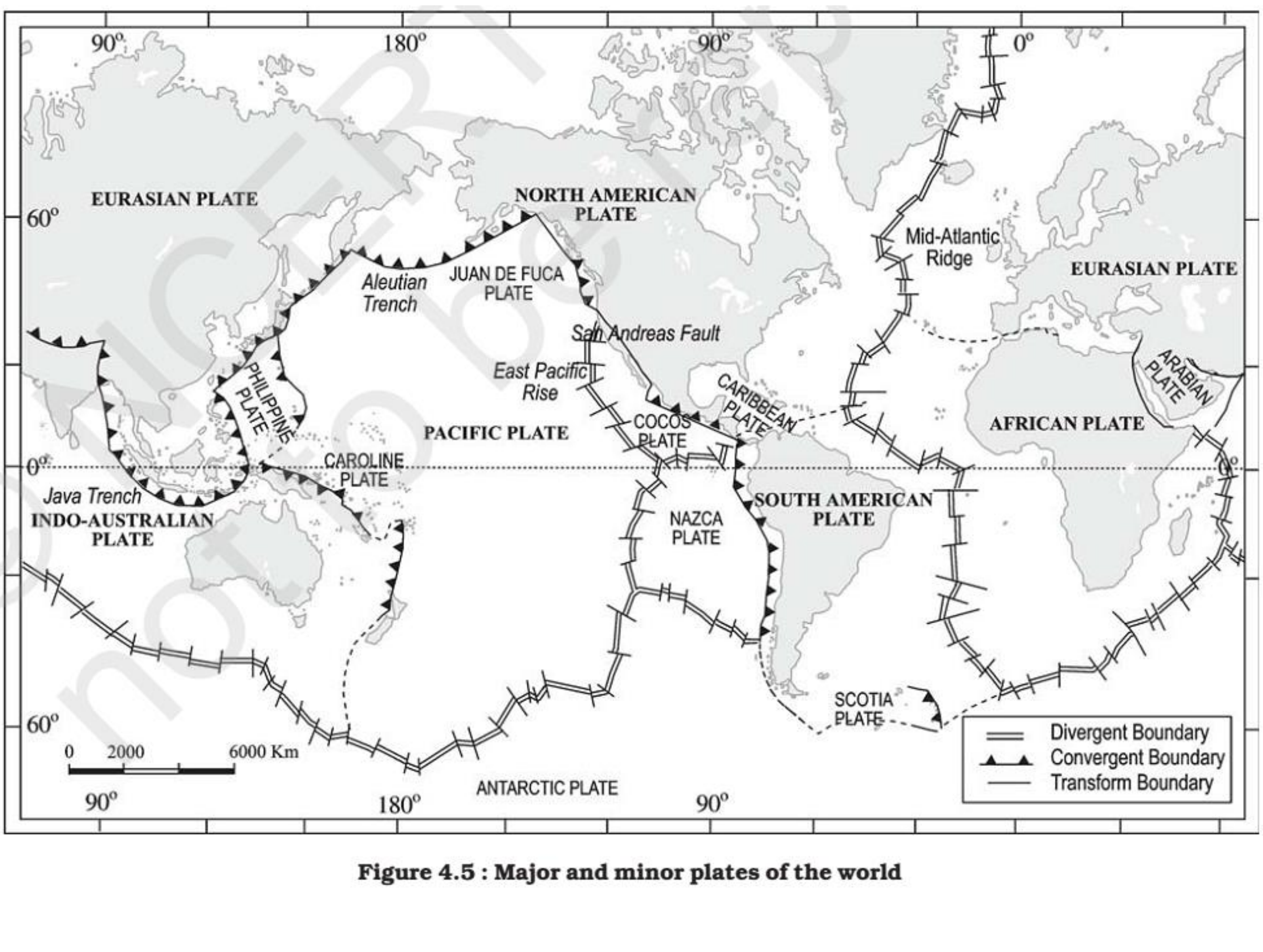
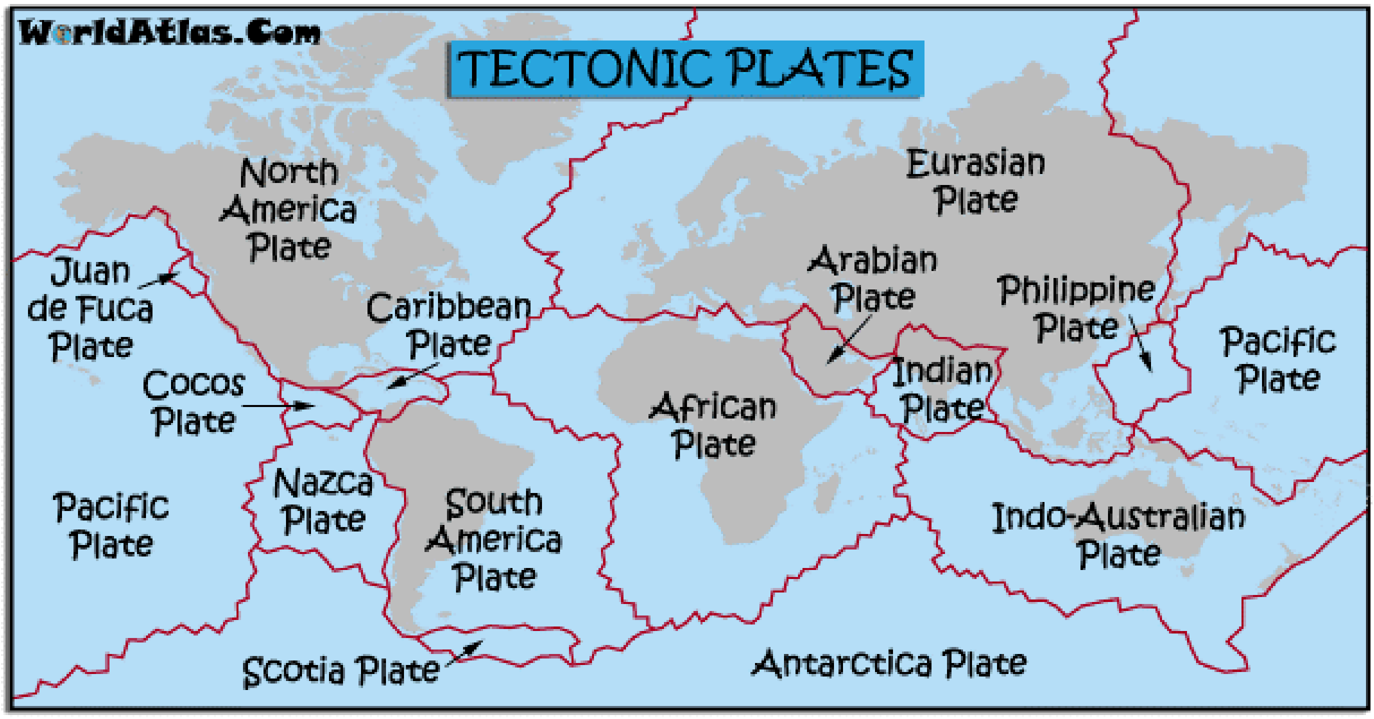


Figure 4.5 : Major and minor plates of the world



6. Fuji plate: North-east of Australia.
7. Turkish plate,
8. Aegean plate (Mediterranean region),
9. Caribbean plate,
10. Juan de Fuca plate (between Pacific and North American plates)
11. Iranian plate.

There are many more minor plates other than the above mentioned plates. Most of the these minor plates were formed due to stress created by converging major plates. Example: the Mediterranean Sea is divided into numerous minor plates due to the compressive force exerted by Eurasian and African plates.

The figure below shows the changes in landform with time due to the interaction of various plates.

Force for the Plate Movement

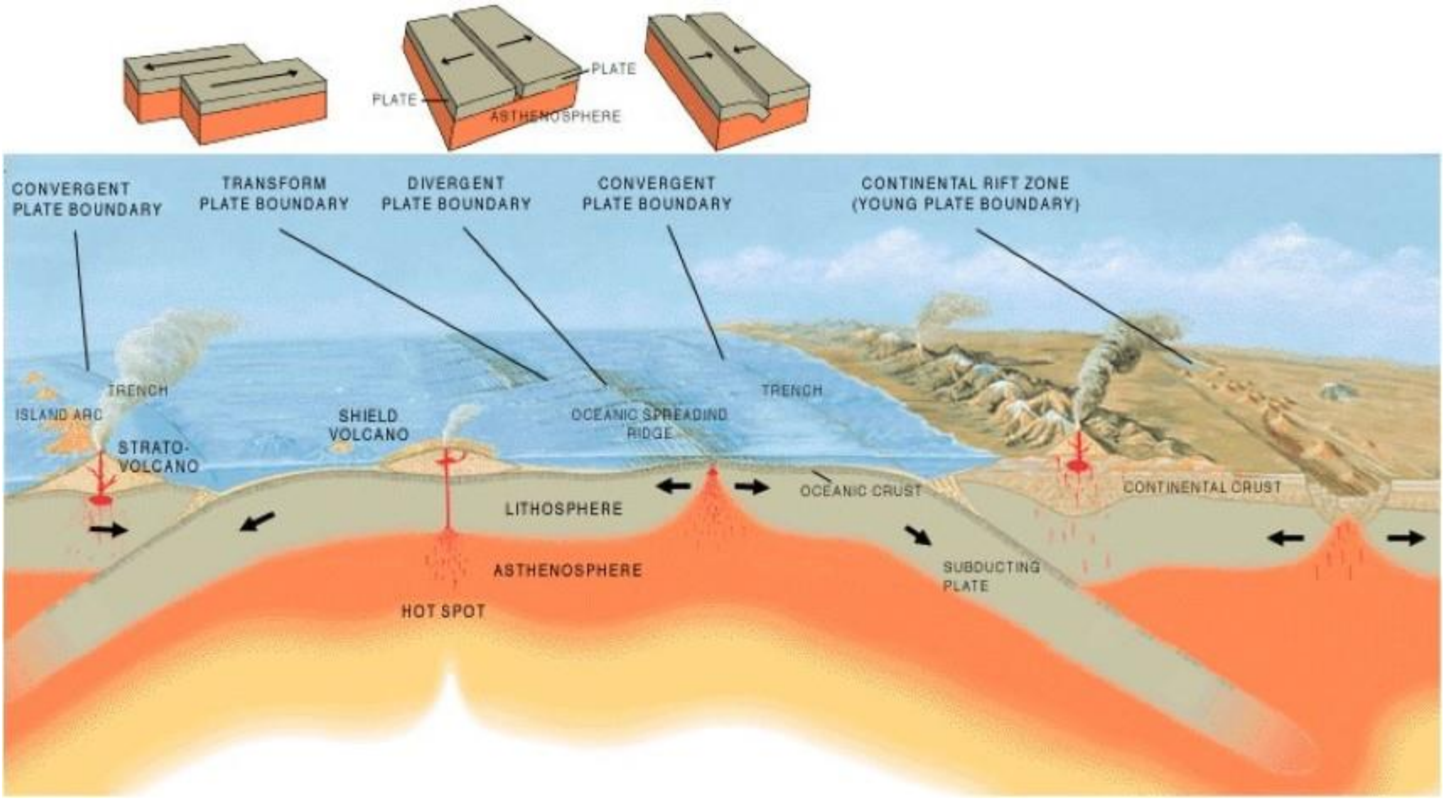
- The **slow movement of hot, softened mantle** that lies below the rigid plates is the driving force behind the plate movement.
- The heated material rises to the surface, spreads and begins to cool, and then sinks back into deeper depths (convection currents – explained in the previous post – See Floor Spreading). This cycle is repeated over and over to generate what scientists call a convection cell or convective flow.
- Heat within the earth comes from two main sources: **radioactive decay** and **residual heat**. Arthur Holmes first considered this idea in the 1930s, which later influenced Harry Hess' thinking about seafloor spreading.

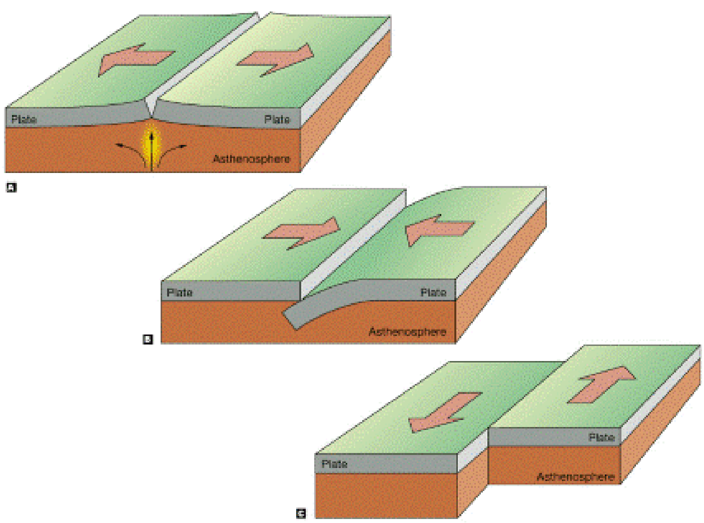
Plate Tectonics - Interaction of Plates

- Major geomorphological features such as fold and block mountains, mid-oceanic ridges, trenches, volcanism, earthquakes etc. are a direct consequence of interaction between various lithospheric plates.
- There are three ways in which the plates interact with each other.

Divergence forming Divergent Edge or the Constructive Edge

- As the name itself suggests, in this kind of interaction, the plates diverge [move away from each other].
- **Mid-oceanic ridges** are formed due to this kind of interaction. Here, the basaltic magma erupts and moves apart (see floor spreading).





- On continents, **East African Rift Valley** is the most important geomorphological feature formed due to divergence of **African and Somali plates**.
- Such edges are sites of earth **crust formation (hence constructive)** and volcanic earth forms are common along such edges.
- Earthquakes (shallow focus) are common along divergent edges.
- The sites where the plates move away from each other are called spreading sites.
- The best-known example of divergent boundaries is the Mid-Atlantic Ridge. At the mid-oceanic ridge in Atlantic ocean, the American Plate(s) is/are separated from the Eurasian and African Plates.

Convergence forming Convergent Edge or Destructive Edge

- In this kind of interaction, two lithospheric plates collide against each other (in detail in the next post).
- The zone of collision may undergo crumpling and folding and folded mountains may emerge.
- This is an orogenic collision. **Himalayan Boundary Fault** is one such example.
- When one of the plates is an oceanic plate, it gets embedded in the **softer asthenosphere** of the continental plate and as a result, **trenches** are formed at the **zone of subduction.**
- The subducted material gets heated, up and is thrown out forming volcanic islands and dynamic equilibrium is achieved
- There are mainly three ways in which convergence can occur.

1. **between an oceanic and continental plate;**

2. **between two oceanic plates; and**
3. **between two continental plates.**

Transcurrent Edge or Conservative Edge or Transform Fault

- Formed when two plates move past each other.
- In this kind of interaction, two plates grind against each other and there is no creation or destruction of landform but only deformation of the existing landform. [Crust is neither produced nor destroyed as the plates slide horizontally past each other].
- In oceans, transform faults are the planes of separation generally perpendicular to the midoceanic ridges.
- San Andreas Fault along the western coast of USA is the best example for a transcurrent edge on continents.

Evidence in Support of Plate Tectonics

- Evidences for both See Floor Spreading and Plate tectonics are **complimentary** (almost same evidences).
- **Paleomagnetic rocks** are the most important evidence. The orientation of iron grains on older rocks shows an orientation which points to the existence of the South Pole, once upon a time, somewhere between the present-day Africa and Antarctica (Paleomagnetism).
- Older rocks form the continents while younger rocks are present on the ocean floor. On continents, rocks of upto 3.5 billion years old can be found while the oldest rock found on the ocean floor is not more than 75 million years old (western part of Pacific floor). As we move, towards ridges, still younger rocks appear. This points to an effective spread of sea floor (See floor spreading is almost similar to plate tectonics except that it examines the interaction between oceanic plates only) along oceanic ridges which are also the plate margins.
- The normal temperature gradient on the sea floor is 9.4°C/300 m but near the ridges it becomes higher, indicating an upwelling of magmatic material from the mantle.
- In trenches, where subduction has taken place (convergent edge), the value of gravitational constant 'g' is less. This indicates a loss of material. For instance, gravity measurements around the Indonesian islands have indicated that large gravity anomalies are associated with the oceanic trench bordering Indonesia.
- The fact that all plate boundary regions are areas of earthquake and volcanic disturbances goes to prove the theory of plate tectonics.

Significance of Plate Tectonics

- For the earth scientists, it is a fundamental principle for study. For physical geographers, this approach is an aid in interpretation of landforms.
- New minerals are thrown up from the core with the magmatic eruptions. Economically valuable minerals like copper and uranium are found more frequently near the plate boundaries.
- On the basis of present knowledge of crustal plate movement, the shape of landmasses in future can be guessed. For instance, if the present trends continue, North and South America will separate. A piece of land will separate from the east coast of Africa. Australia will move closer to Asia.

Movement Of The Indian Plate

- The Indian plate includes Peninsular India and the Australian continental portions.

Indian Plate Boundaries

- The subduction zone along the **Himalayas** forms the northern plate boundary in the form of continent — continent convergence.
- In the east, it extends through Rakinyoma Mountains (Arakan Yoma) of Myanmar towards the island arc along the Java Trench. The eastern margin is a spreading

site lying to the east of Australia in the form of an oceanic ridge in SW Pacific.

- The Western margin follows **Kirthar Mountain** of Pakistan. It further extends along the **Makrana coast** (Pakistan and Iranian coasts) and joins the spreading site from the **Red Sea rift (Red Sea rift is formed due to divergence of Somali plate and Arabian plate)** southeastward along the **Chagos Archipelago (Formed due to hotspot volcanism).**
- The boundary between India and the Antarctic plate is also marked by oceanic ridge (divergent boundary) running in roughly W-E direction and merging into the spreading site, a little south of New Zealand.

Movement

- India was a large island situated off the Australian coast, in a vast ocean.
- The **Tethys Sea** separated it from the Asian continent till about 225 million years ago.
- India is supposed to have started her northward journey about 200 million years ago at the time when **Pangaea** broke.
- India collided with Asia about **40-50 million years ago** causing rapid uplift of the Himalayas.
- The positions of India since about 71 million years till the present are shown in the Figure. It also shows the position of the Indian subcontinent and the Eurasian plate.
- About 140 million years before the present, the subcontinent was located as south as 50◦ S. latitude. The two major plates were separated by the **Tethys Sea** and the Tibetan block was closer to the Asiatic landmass.
- During the movement of the Indian plate towards the Asiatic plate, a major event that occurred was the outpouring of lava and formation of the **Deccan Traps**. This started somewhere around **60 million years ago** and continued for a long period of time.

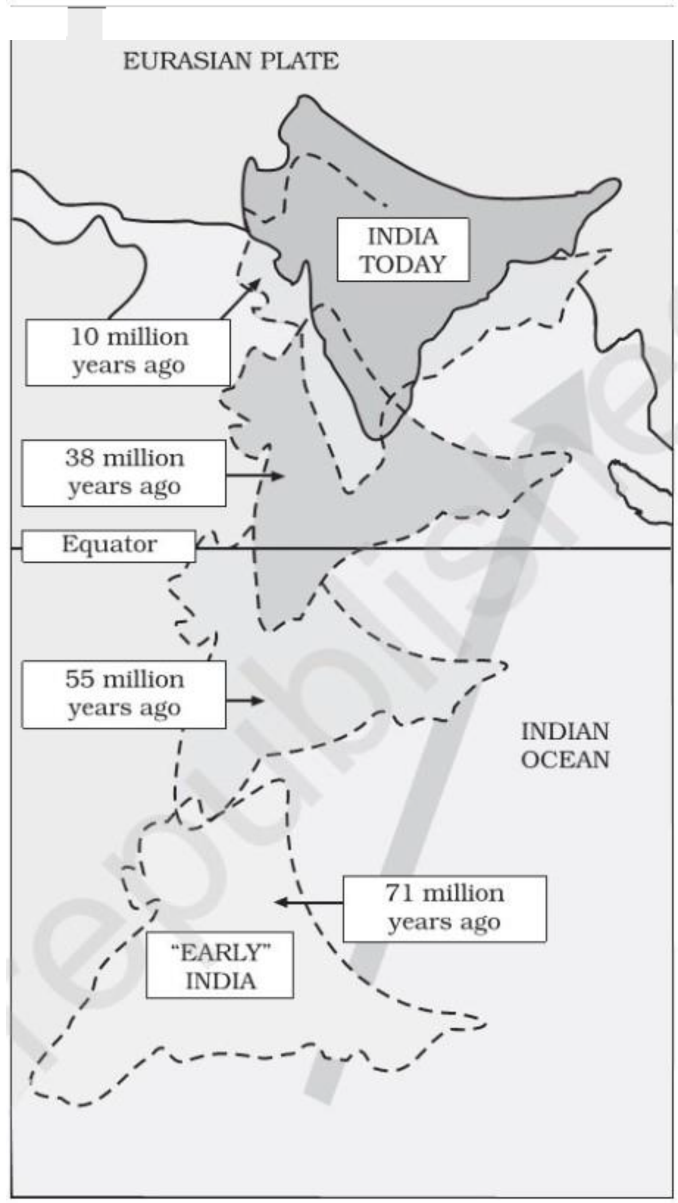


Figure 4.6 : Movement of the Indian plate

- Note that the subcontinent was still close to the equator. From **40 million years ago and thereafter**, the event of formation of the Himalayas took place.
- Scientists believe that the process is still continuing and the height of the Himalayas is rising even to this date.

In short

- Around 220 million years ago, around the time that Pangea was breaking apart, India started to move northwards.
- It travelled some 6,000 kilometres before it finally collided with Asia around 40 to 50 million years ago.
- Then, part of the Indian landmass began to go beneath the Asian plate, moving the

Asian landmass up, which resulted in the rise of the Himalayas.

- It's thought that India's coastline was denser and more firmly attached to the seabed, which is why Asia's softer soil was pushed up rather than the other way around.
- The mountain range grew very rapidly in comparison to most mountain ranges, and it's actually still growing today.
- The continued growth in the Himalayas is likely due to the Indian tectonic plate still moving slowly but surely northward. We know the plate is still moving in part because of the frequent earthquakes in the region.

Comparison: Continental Drift – See Floor Spreading – Plate Tectonics

	Continental Drift	**See Floor Spreading**	**Plate Tectonics**
Explained by	**Alfred Wegener** in 1920s	**Arthur Holmes** explains Convectional Current Theory in 1930s. Based on convectional current theory, **Harry Hess** explains See Floor Spreading in 1940s	In 1967, McKenzie and Parker suggested the theory of plate tectonics. The theory was later outlined by Morgan in 1968
Theory	Explains Movement of Continents only	Explains Movement of Oceanic Plates only	Explains Movement of Lithospheric plates that include both continents and oceans.
Forces for movement	Buoyancy, gravity, pole fleeing force, tidal currents, tides,	Convection currents in the mantle drag crustal plates	Convection currents in the mantle drag crustal plates
Evidences	Apparent affinity of physical features, botanical evidence, fossil evidence, Tillite deposits, placer deposits, rocks of same age across different continents etc.	Ocean bottom relief, Paleomagnetic rocks, distribution of earthquakes and volcanoes etc.	Ocean bottom relief, Paleomagnetic rocks, distribution of earthquakes and volcanoes, gravitational anomalies at trenches, etc.
Drawbacks	Too general with silly and sometimes illogical evidences.	Doesn't explain the movement of continental plates	---------------------
Acceptance	Totally discarded	Not complete	Most widely accepted
Usefulness	Helped in the evolution of convectional current theory and see floor spreading theory	Helped in the evolution of plate tectonics theory	Helped understand various geographical features.

Multiple choice questions.

1. Polar fleeing force relates to:
1) Revolution of the Earth
2) Rotation of the earth
3) Gravitation
4) Tides

2. Which one of the following is not a minor plate?
1) Nazca
2) Philippines
3) Arabia
4) Antarctica

3. Which one of the following facts was not considered by those while discussing the concept of sea floor spreading?
1) Volcanic activity along the mid-oceanic ridges.
2) Stripes of normal and reverse magnetic field observed in rocks of ocean floor.
3) Distribution of fossils in different continents.
4) Age of rocks from the ocean floor.
4. Which one of the following is the type of plate boundary of the Indian plate along the Himalayan mountains?
1) Ocean-continent convergence
2) Divergent boundary
3) Transform boundary
4) Continent-continent convergence

Answer in about 30 words.

1. What were the forces suggested by Wegener for the movement of the continents?
2. How are the convectional currents in the mantle initiated and maintained?
3. What is the major difference between the transform boundary and the convergent or divergent boundaries of plates?
4. What was the location of the Indian landmass during the formation of the Deccan Traps?

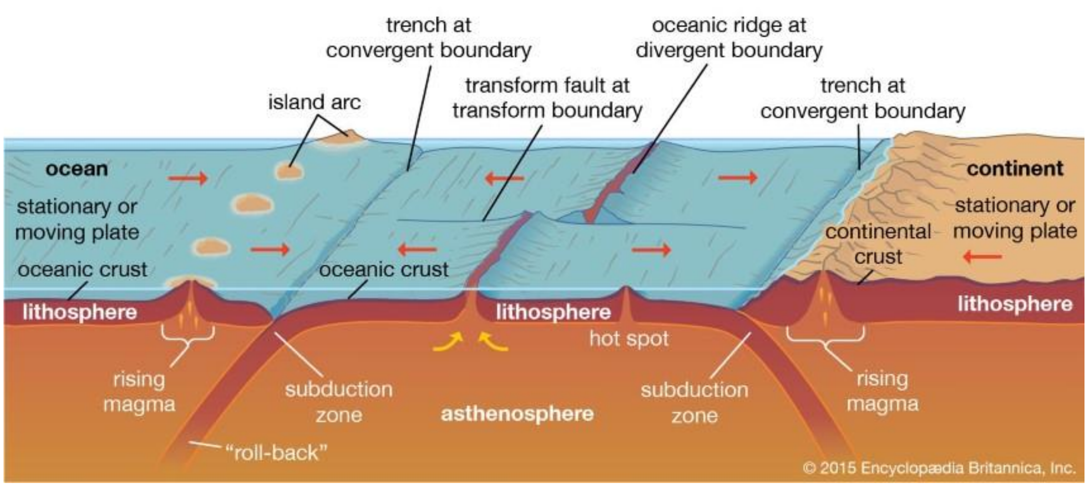
Answer in about 150 words

1. What are the evidences in support of the continental drift theory?
2. Bring about the basic difference between the drift theory and Plate tectonics.
3. What were the major post-drift discoveries that rejuvenated the interest of scientists in the study of distribution of oceans and continents?

In this post we will study about **Ocean - Ocean Convergence**. Understanding Ocean - Ocean Convergence helps us in understanding the **formation of Japanese Island Arc, formation of Indonesian Archipelago, formation of Philippine Island Arc and formation of Caribbean Islands.**

Previous mains question: "Explain the formation of thousands of islands in Indonesian and Philippines archipelagos."

In the previous post, we have studied about **Plate Tectonics, Interaction of plates – Convergence, Divergence etc.**



In convergence there are subtypes namely:

1. **Collision of oceanic plates or ocean - ocean convergence.**
2. **Collision of continental and oceanic plates or ocean - continent convergence.**
3. **Collision of continental plates or continent - continent convergence.**
4. **Collision of continent and arc or continent - arc convergence.**

In this post we will stick to Ocean – Ocean Convergence. Remaining types will be explained in future posts.

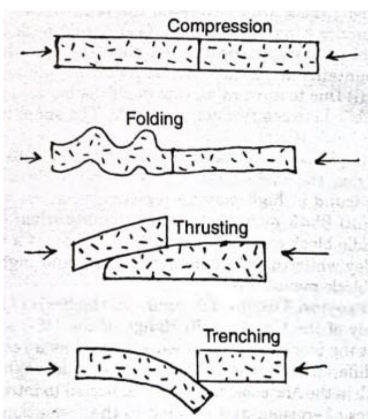
Basics

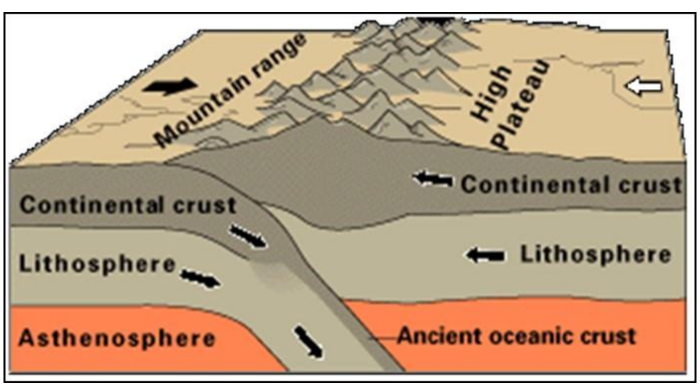
Ocean - Ocean Convergence or The Island - Arc Convergence

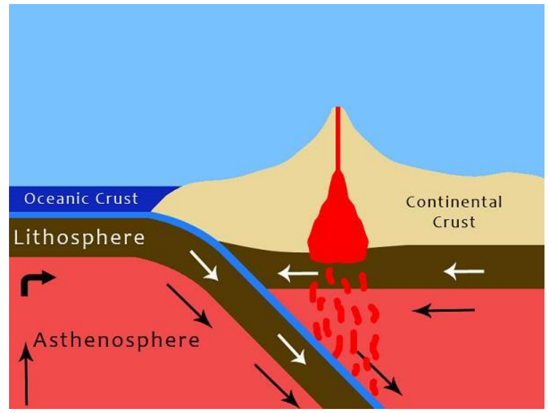
- In Ocean - Ocean Convergence, a **denser oceanic plate** subducts below a **less denser oceanic plate** forming a **trench** along the boundary.

  [We have studies in the previous post on See Floor Spreading how convectional currents in the mantle drive the lithospheric plates]

- As the ocean floor crust (oceanic plate) loaded with sediments subducts into the softer **asthenosphere**, the rocks on the continental side in the subduction zone become **metamorphosed** under high pressure and temperature.

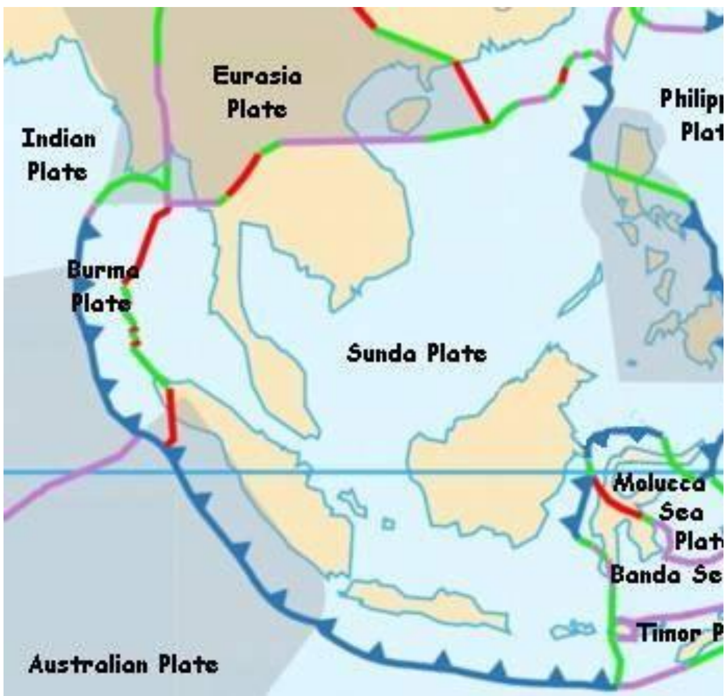






- After reaching a depth of about 100 km, plates melt. Magma (**metamorphosed sediments and the melted part of the subducting plate**) has lower density and is at high pressure. It rises upwards due to the buoyant force offered by surrounding denser medium. The magma flows out, sometimes violently to the surface.
- A continuous upward movement of magma creates constant volcanic eruptions at the ocean floor.
- Constant volcanism above the subduction zone creates layers of rocks. As this process continues for millions of years, a volcanic landform is created which in some cases rises above the ocean waters.
- Such volcanic landforms all along the boundary form a chain of volcanic islands which are collectively called as Island Arcs (Indonesian Island Arc or Indonesian Archipelago, Philippine Island Arc, Japanese Island Arc etc.).
- Orogenesis sets in motion the process of **building continental crust by replacing oceanic crust** (this happens at a much later stage. For example, new islands are born around Japan in every few years. After some million years Japan will be a single landmass because continental crust formation is constantly replacing the oceanic crust [more and more volcanism creates much bigger landform]).

This explanation is common for all the island arc formations due to ocean - ocean convergence. In addition, we only need to know the plates involved with respect to each island formation.



Formation of Philippine Island Arc System

- For the study of the formation of the Philippine islands, the most important of the major plates are: the **Sunda Plate** (major continental shelf of **Eurasian plate)** and the **Philippine Sea plate.**

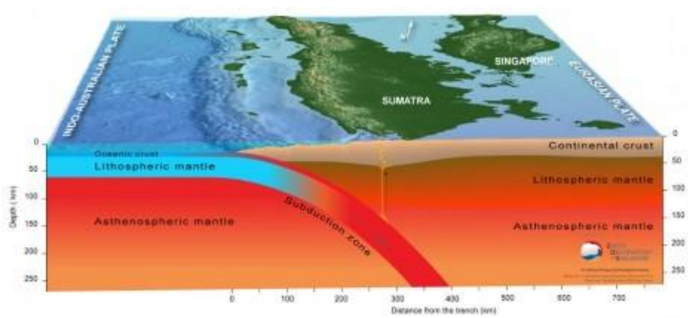
https://upload.wikimedia.org/wikipedia/commons/b/b4/Plate_tectonics_map.gif

[The extreme southeastern portion of the Eurasian plate, which is a part of Southeast Asia, is a **continental shelf**. The region is called the **Sunda Shelf**. The Sunda Shelf and its islands is known as the **Sundaland block of the Eurasian plate]**.

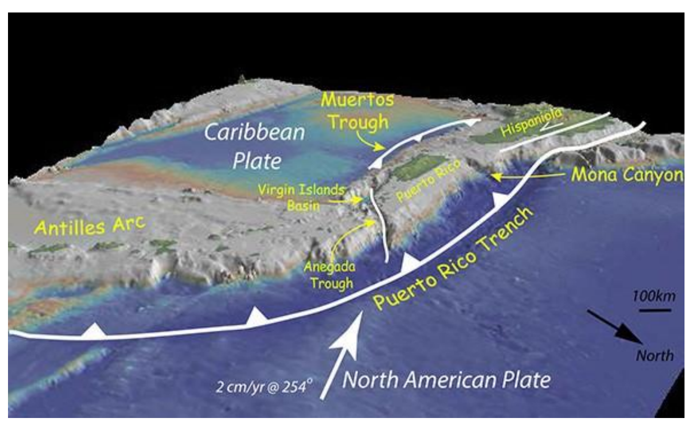
- Philippine Island Arc system is formed due to subduction of **Philippine Sea plate** under **Sunda Plate** (part of Eurasian Plate). The trench formed here is called **Philippine Trench.**

Formation of Indonesian Archipelago

- In case of Indonesian Archipelago, **Indo-Australian plate** subducts below **Sunda Plate (part of Eurasian Plate).** The trench formed here is called **Sunda trench (Java Trench is a major section of Sunda trench).**



Formation of Caribbean Islands

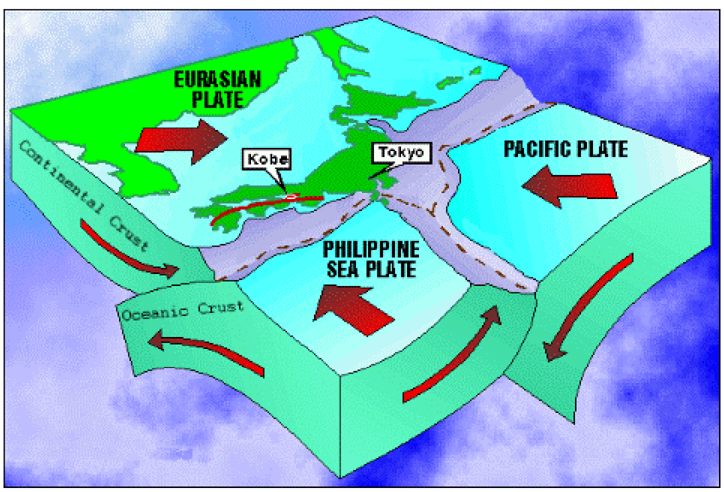


- Formation of Caribbean Islands is also similar but here the plate interaction is complex due to the involvement of many minor plates.
- **North American Plate** subducts under the **Caribbean plate** and forms the **Puerto**

Rico Trench. There is trough formation on the other side as well.

Formation of Japanese Island Arc

- Japan's volcanoes are part of three volcanic arcs.
- The arcs meet at a triple junction on the island of Honshu.
- Northern arc is formed due to the subduction of the **Pacific Plate** under the **Eurasian Plate**. The trench formed is **Japan Trench.**
- Central arc is formed due to the subduction of the **Pacific Plate** under the **Philippine Plate** (island formation is not significant along this arc). The trench formed is **Izu Trench.**
- Southern Arc is formed due to the subduction of the **Philippine Plate** under the **Eurasian Plate.** The trench formed is **Ryukyu Trench.**



- Japanese island arc was very close to the mainland.
- The force exerted by the Pacific plate and the Philippine plate tilted the arc towards its east giving rise to the **Sea of Japan.**

Explain the formation of thousands of islands in Indonesian and Philippines archipelagos

[20 marks - Mains 2014]

I suggest you to rely on mrunal.org answer key to know how to write an answer.

Archipelago: an extensive group of islands. [All the above mentioned ones and + few more]

Island arc: narrow chain of islands which are volcanic in origin. Island arc is usually curved. The convex side will have a trench if it's an oceanic arc. Japan, Philippines, Hawaii etc. are oceanic arcs. Cascade range, Western Chile range etc. are examples of continental arcs.

Model Answer [May not be ideal, there is always scope for optimization] [I followed the formula 20 marks = 200 words]

- Indonesian archipelago and Philippine archipelago are located along the **plate margins**. Both the archipelagoes were formed due to **ocean – ocean convergence**.
- Indonesian archipelago was formed due to convergence between Sunda oceanic plate (part of Eurasian plate) and Indo – Australian plate whereas Philippine archipelago was formed due to convergence between Sunda oceanic plate and Philippine Sea plate. [if you can't remember names, you should avoid these kind of points]
- In ocean – ocean convergence, two oceanic plates converge or collide. The denser plate subducts into the **asthenosphere** below the convergence zone and forms a **trench** at the surface. This region below the convergence zone is called the **zone of subduction**.
- In the zone of subduction, due to high temperature and pressure, the rocks undergo **metamorphosis** and the

sediments in the oceanic plate melt to form **magma**.

- The magma being lighter moves upwards. It is at high pressure due to the buoyant force offered by the surrounding **denser medium**. At the surface magma escapes in the form of volcanic eruptions.
- The magma solidifies creating a volcanic layer. **Subsequent volcanism** builds layer over layer and a volcanic mountain if formed. Such mountains are formed all along the converging edge above the less denser plate.
- Over time the mountains merge and oceanic crust **gets transformed** into continental crust.
- And this is how Indonesian archipelago and Philippine archipelago are formed.

[Figure must for this answer]

[211 words] [you can always optimize an answer by addition or deletion] [I tried my best to keep this answer relevant] [If you have a better answer, write it in the comments]

If asked for 10 marks = 100 words.

- Indonesian and Philippine archipelagos are formed due to **ocean – ocean convergence**.
- In ocean – ocean convergence, the denser plate subducts into the **asthenosphere**. This region below the convergence zone is called the **zone of subduction**.
- In the zone of subduction the rocks undergo **metamorphosis** and the **sediments** in the oceanic plate melt to form **magma**.
- At the surface magma escapes in the form of volcanic eruptions.
- constant **volcanism** builds layer over layer and a volcanic mountain if formed.
- Such mountains are formed all along the converging edge.
- Over time the mountains merge and oceanic crust **gets transformed** into continental crust.
- And this is how Indonesian archipelago and Philippine archipelago are formed.

Related question

In spite of extensive volcanism, there is no island formation along the divergent boundary (mid oceanic ridge)

- **Basaltic magma** flows out along the divergent edge (Fissure type volcano).
- Basaltic magma = **less silica** = less viscosity = flows over a large distance and hence causes see floor spreading but not volcanic islands.
- On the other hand, along convergent boundary, andesitic or acidic magma flows out.
- **Andesitic or acidic magma** = **more silica** content = higher viscosity = doesn't move quick and also solidifies quickly. This helps in building layer over layer in a narrow region = huge volcanic mountain.

In this post we will study about **Continent - Ocean Convergence**. Understanding Continent - Ocean Convergence is important to understand the **Fromation of The Rockies**, the **Formation of the Andes** and other similar **fold mountain systems**.

We have studied in See Floor Spreading how convectional currents in the mantle drive the lithospheric plates. Rising vertical limbs of the convection currents in the mantle create a divergent plate boundary and falling limbs create a convergent plate boundary.

In convergence there are sub-types namely:

1. Collision of oceanic plates or ocean - ocean convergence. [Explained in the previous post]
2. Collision of continental and oceanic plates or ocean - continent convergence [This post].
3. Collision of continental plates or continent - continent convergence [Next Post].
4. Collision of continent and arc or continent - arc convergence [Next Post].

In all types of convergence, **denser plate subducts** and the less denser plate is either up **thrust or folded or both** [up thrust and folded].

Continent - Ocean Convergence Or The Cordilleran Convergence

- Continent - Ocean Convergence is also called Cordilleran Convergence because this kind of convergence gives rise to extensive mountain systems. A cordillera is an extensive chain of mountains or mountain ranges. Some mountain chains in North America and South America are called cordilleras.
- Continent - Ocean Convergence is similar to ocean - ocean convergence. One important difference is that in continent - ocean convergence mountains are formed instead of islands.
- When oceanic and continental plates collide or converge, the oceanic plate (denser plate) subducts or plunges below the continental plate (less denser plate) forming a **trench** along the boundary. The trenches formed here are not as deep as those formed in ocean - ocean convergence.
- As the ocean floor crust (oceanic plate) loaded with **sediments** subducts into the softer asthenosphere, the rocks on the continental side in the subduction zone become **metamorphosed** under high pressure and temperature.
- After reaching a certain depth, plates melt. Magma (metamorphosed sediments and the melted part of the subducting plate) has lower density and is at high pressure. It rises upwards due to the buoyant force offered by surrounding denser medium. The magma flows out, sometimes violently to the surface.
- A continuous upward movement of magma creates constant volcanic eruptions at the surface of the continental plate along the margin.
- Such volcanic eruptions all along the boundary form a chain of volcanic mountains which are collectively called as **continental arc**.

[**Arc:** narrow chain of volcanic islands or mountains.

Island arc: A narrow chain of volcanic islands. Island arc is usually curved. The convex side will have a trench if it's an oceanic arc. **Japan, Philippines, Hawaii** (hotspot island arc) etc. are oceanic arcs. They are formed due to ocean - ocean convergence.

Continental arc: A narrow chain of volcanic mountains on continents. **Cascade range (parallel to Rockies), Western Chile range (parallel to Andes)** etc. are examples of continental arcs. They are formed due to continent - ocean convergence]

- Continental margins are filled with thick geoclinal sediments brought by the rivers. As a result of convergence, the buoyant granite [geoclinal sediments] of the continental crust overrides (is placed above) the oceanic crust [continental crust in up thrust by the oceanic crust]. As a result the edge of the deformed continental margin is thrust above sea level.
- The advancing oceanic plate adds more compressive stress on the up thrust continental margin and leads to its **folding** creating a fold mountain system.
- In some cases, the advancing oceanic plate compresses the **continental arc (orogenic belt)** leading to its folding **(Rockies and Andes).**

[As the oceanic plate subducts, the sediments brought by it accumulates in the trench region. These accumulated sediments are called as **accretionary wedge**. The accretionary wedge is compressed into the continental margin leading to **crustal shortening**.

Convergence == Crustal Shortening

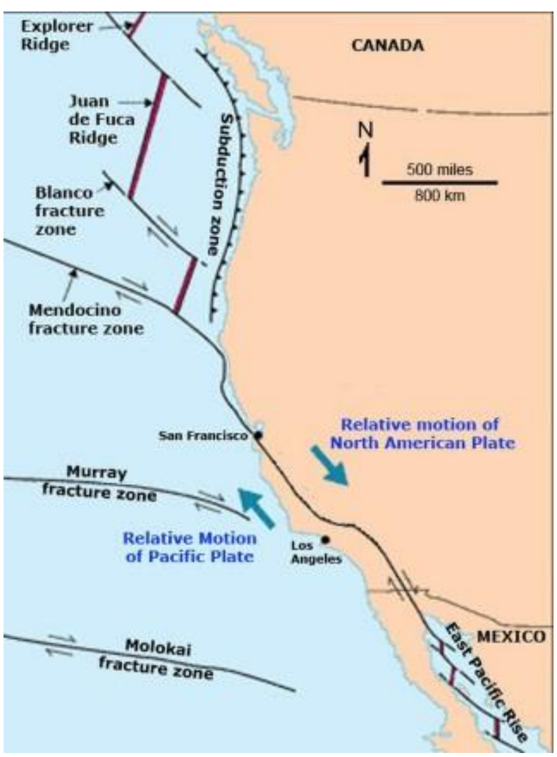
Divergence == Crustal Widening

Crustal Shortening at one place is compensated by Crustal Widening in some other place]

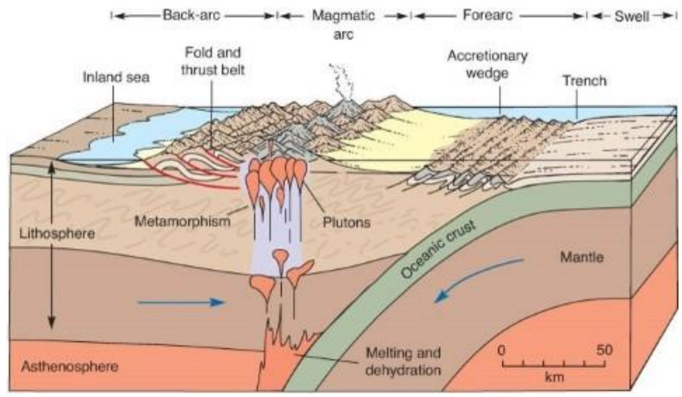
- With the formation of the orogenic belt (fold mountain belt), resistance builds up which effectively stops convergence. Thus, the subduction zone progresses seaward.
- With the culmination of compression, erosion continues to denude mountains. This results in isostatic adjustment which causes ultimate exposure of the roots of mountains.
- Examples are found in the **Rockies**, deformed in late Mesozoic and early Tertiary period, and the **Andes**, where the deformation begun in the Tertiary Period is still going on.

Formation of the Andes - Continent - Ocean Convergence

- The Andes are formed due to convergence between **Nazca plate** (oceanic plate) and the **South American plate** (continental plate). **Peru – Chile trench** is formed due to subduction of Nazca plate.
- Andes are a continental arc (narrow, continental volcanic chain) formed due to the volcanism above the subduction zone. The pressure offered by the **accretionary wedge** folded the volcanic mountain, raising the mountains significantly.



- The folding process in Andes is still continuing and the mountains are constantly rising.
- Volcanism is still active. **Ojos del Salado active volcano** on the Argentina – Chile border is the highest active volcano on earth at 6,893 m. (**Olympus Mons** on Mars is the highest volcano in the solar system. It is 26 – 27 km high)
- **Mount Aconcagua** (6,960 m, Argentina), the highest peak outside Himalayas and the highest peak in the western hemisphere is an extinct volcano.

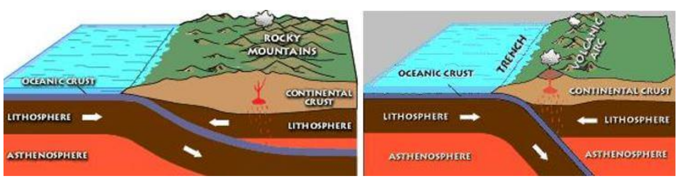


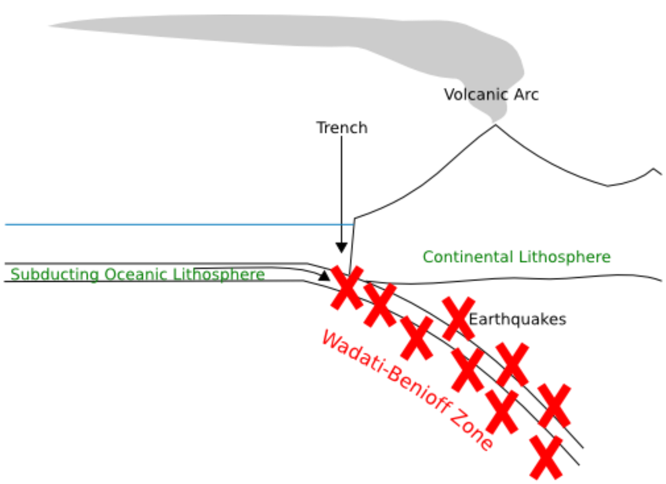
Formation of the Rockies - Continent - Ocean Convergence

- The **North American plate** (continental plate) moved west wards while the **Juan de Fuca plate** (minor oceanic plate) and the **Pacific plate** (major oceanic plate) moved eastwards. The convergence gave rise to a series of parallel mountain ranges.
- Unlike the Andes, the Rockies are formed at a distance from the continental margin due to the less steep subduction by the oceanic plates.
- Trenching is less conspicuous as the boundary is filled with accretionary wedge and there are a series of fault zones that makes the landforms a bit different from Andes.

Wadati - Benioff zone: Earthquakes along Convergent boundary

- A Wadati–Benioff zone is a zone of seismicity corresponding with the down-going slab in a subduction zone (the intensity of earthquakes increases with depth of subduction).
- Differential motion along the zone produces numerous earthquakes, the foci of which may be as deep as about 670 kilometres.
- Wadati–Benioff zone earthquakes develop beneath volcanic island arcs and continental margins above active subduction zones.
- They can be produced by slip along the subduction thrust fault or slip on faults within the down going plate.
- Most disastrous earthquakes are deep seated ones or deep focus earthquakes. Such earthquakes are common around the subduction zone.





Chile, Japan, Himalayan belt see high intensity disastrous earthquakes due to the subduction process.

We will study about the formation of Himalayas in the next post.

In this post we will study about Continent - Continent Convergence. Understanding Continent - Continent Convergence is important to understand the Formation of the Himalayas, the Alps, the Urals and the Atlas mountains.

We have studied in See Floor Spreading how convectional currents in the mantle drive the lithospheric plates. Rising vertical limbs of the convection currents in the mantle create a divergent plate boundary and falling limbs create a convergent plate boundary.

In convergence there are sub-types namely:

1. Collision of oceanic plates or ocean - ocean convergence. [Explained in the previous posts]
2. Collision of continental and oceanic plates or ocean - continent convergence [Explained in the previous post].
3. Collision of continental plates or continent - continent convergence [This Post].
4. Collision of continent and arc or continent - arc convergence [This Post].

In all types of convergence, **denser plate subducts** and the less denser plate is either up **thrust or folded or both** [up thrust and folded].

Continent - Continent Convergence or The Himalayan Convergence

- In ocean – ocean convergence and continent – ocean convergence, **at least one of the plates is denser** and hence the subduction zone is **quite deep** [few hundred kilometers].
- At continental – continental convergent margins, due to **lower density**, both of the continental crustal plates are too light [too buoyant] to be carried downward (subduct) into a trench. In most cases, neither plate subducts or even if one of the plates subducts, the subduction zone will not go deeper than 40 – 50 km.
- The two plates converge, buckle up [The subduction of the continental crust is not

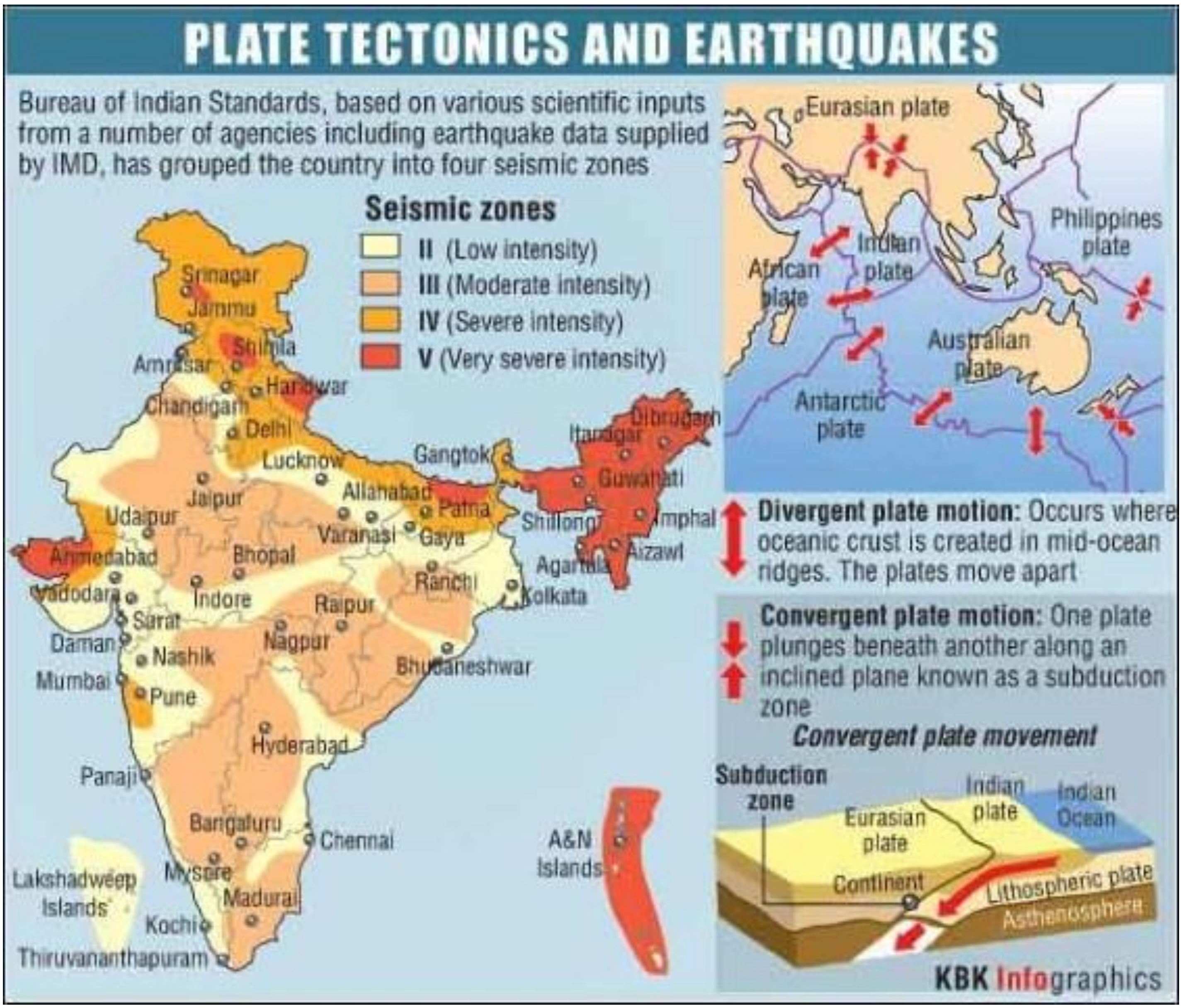
possible beyond 40 km because of the normal buoyancy of the continental crust. Thus, the fragments of oceanic crust are plastered against the plates causing welding of two plates known as **suture zone.** Example: The- Indus-Tsangpo suture zone], fold, and fault.

- Geoclinal sediments are found along the continental margins. As the continental plates converge, the ocean basin (geosynclinical basin) is squeezed between the two converging plates. Huge slivers of rock, many kilometers wide are thrust on top of one another, forming a towering mountain ranges.
- With the building up of resistance, convergence comes to an end. The mountain belt erodes and this is followed by isostatic adjustment.
- As two massive continents weld, a single large continental mass joined by a mountain range is produced.
- Examples: **The Himalayas, Alps, Urals, Appalachians** and **the Atlas mountains.**

Volcanism and Earthquakes in Continent - Continent Convergence

SIGNIFICANT QUAKES IN & AROUND INDIA

DATE	REGION	MAGNITUDE
1819 Jun 16	KUTCH, GUJARAT	8.0
1885 May 30	SOPORE, JAMMU & KASHMIR	7.0
1897 Jun 12	SHILLONG PLATEAU	8.7
1905 Apr 4	KANGRA, HIMACHAL PRADESH	8.0
1934 Jan 15	BIHAR-NEPAL BORDER	8.3
1941Jun 26	ANDAMAN ISLANDS	8.1
1950 Aug 15	ARUNACHAL PRADESH-CHINA BORDER	8.5
2001 Jan 26	BHUJ, GUJARAT	7.7
2004 Dec 26	OFF WEST COAST OF SUMATRA	9.[illegible]



- Oceanic crust is only 5 – 30 km thick. But the continental crust is 50 – 70 km thick. Magma cannot penetrate this thick crust, so there are **no volcanoes**, although the magma stays in the crust.
- **Metamorphic rocks** are common because of the stress the continental crust experiences.
- With enormous slabs of crust smashing together, continent – continent collisions bring on numerous and **large earthquakes**. [Earth Quakes in Himalayan and North Indian Region]

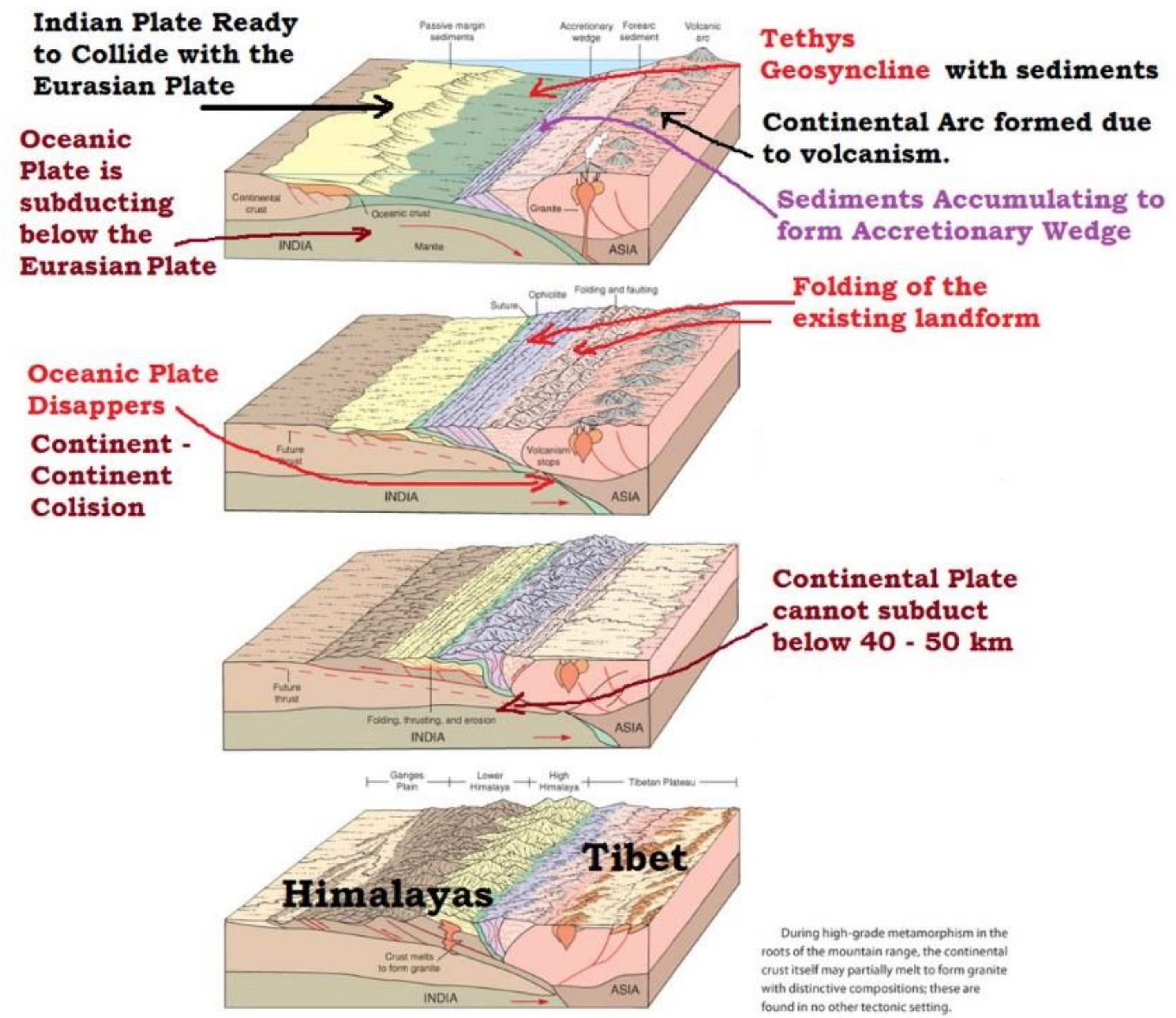
Convergent boundary = More deep focus earthquakes. Example: Kachchh region, Himalayan region.

Formation of Himalayans and Tibet

- The Himalayan mountains are also known as the **Himadri, Himavan or Himachal**.
- The Himalayas are a part of **Alpine mountain Chain**.
- The Himalayas are the **youngest mountain chain** in the world.

Indo-Australian Plate

- Indo – Australian plate ➔ Indian plate + Australian plate + Some parts of Indian Ocean.



Indo – Australian Plate boundary

- North ==> Himalayas
- East ==> Purvanchal, Rakinyoma Mountains, Arakan coast, Andaman & Nicobar islands and Java Trench, South western Pacific plate.
- West ==> Suleiman and Kirthar ranges, Makrana coast, western margin of Red Sea rift, Spreading site between Indio – Australian plate and African plate
- South ==> Spreading site between Indio – Australian plate and Antarctic plate

Explain the formation of Himalayas

- Himalayan mountains have come out of a **great geosyncline** called the **Tethys Sea** and that the uplift has taken place in different phases.
- During **Permian Period (250) million years ago**, there was a super continent known as **Pangaea.**
- Its northern part consisted of the present day North America and Eurasia (Europe and Asia) which was called **Laurasia or Angaraland or Laurentia**.
- The southern part of Pangaea consisted of present day South America, Africa, South India, Australia and Antarctica. This landmass was called **Gondwanaland.**
- In between Laurasia and Gondwanaland, there was a long, narrow and shallow sea known as the **Tethys Sea** (All this was explained in detail in Continental Drift Theory).
- There were many rivers which were flowing into the Tethys Sea (Older than Himalayas. We will see this in detail while studying Antecedent and Subsequent Drainage).
- Sediments were brought by these rivers and were deposited on the floor of the Tethys Sea.
- These sediments were subjected to powerful compression due to the northward movement of the Indian Plate. This resulted in the folding of sediments.
- Once the Indian plate started plunging below the Eurasian plate, these sediments were further folded and raised. This process is still continuing (India is moving northwards at the rate of about **five cm per year** and crashing into rest of the Asia).
- And the folded sediments, after a lot of erosional activity, appear as present day Himalayas.
- Tibetan plateau was formed due to up thrusting of the Eurasian Plate. And the Indo-Gangetic plain was formed due to consolidation of alluvium brought down by the rivers flowing from Himalayas.
- The curved shape of the Himalayas convex to the south, is attributed to the maximum push offered at two ends of the Indian Peninsula during its northward drift.
- Himalayas do not comprise a single range but a series of at least three ranges running more or less parallel to one another.
- Therefore, the Himalayas are supposed to have emerged out of the Himalayan Geosyncline i.e. the Tethys Sea in three different phases following one after the other.
- The first phase commenced about **50-40 million years ago**, when the **Great Himalayas** were formed. The formation of the Great Himalayas was completed about 30 million years ago.
- The second phase took place about **25 to 30 million years ago** when the **Middle Himalayas** were formed.
- The Shiwaliks were formed in the last phase of the Himalayan orogeny — say about two million to twenty million years ago.
- Some of the fossil formations found in the Shiwalik hills are also available in the Tibet plateau. It indicates that the past climate of the Tibet plateau was somewhat similar to the climate of the Shiwalik hills.
- There are evidences to show that the process of uplift of the Himalayas is not yet complete and they are still rising.
- [Recent studies have shown that convergence of the Indian plate and the Asian plate has caused a crustal shortening of about 500 km in the

Himalayan region. This shortening has been compensated by sea floor spreading along the oceanic ridge in the Indian Ocean]

Formation of Himalayas in Short

- Pangea's breakup starts in **Permian period [225 million years ago].**
- India started her northward journey about **200 million years** ago.
- It travelled some 6,000 kilometres before it finally collided with Asia.
- India collided with Asia about **40-50 million years ago.**
- Convergent boundary gave rise to Himalayas 40 – 50 million years ago **[Tertiary Period]** [Formation of Deccan Traps began 70-60 million years ago]
- Scientists believe that the process is still continuing and the height of the Himalayas is rising even to this date.

Evidences for the rising Himalayas

- Today's satellites that use high precision atomic clocks can measure accurately even a small rise of one cm. The heights of various places as determined by satellites indicate that the Himalayas rise by few centimeters every year. The present rate of uplift of the Himalayas has been calculated at 5 to 10 cm per year.
- Due to uplifting, lakes in Tibet are desiccated (lose water) keeping the gravel terraces at much higher levels above the present water level. This could be possible only in the event of uplift of the region.
- The frequent tectonic activity (occurrence of earthquakes) in the Himalayan region shows that the Indian plate is moving further northwards and plunging into Eurasian plate. This means that the Himalayas are still being raised due to compression and have not yet attained **isostatic equilibrium**.
- The Himalayan rivers are in their youthful stage and have been rejuvenated [make or cause to appear younger or more vital] in recent times. This shows that the Himalayan Landmass is rising keep the rivers in youth stage since a long time.

Formation of Alps, Urals, Appalachians and the Atlas mountains

- The formation of each of these mountains is similar to the formation of the Himalayas.
- Alps are young fold mountains which were formed due to collision between African Plate and the Eurasian Plate.
- Atlas mountains are also young folded mountains which are still in the process of formation. They are also formed due to collision between African Plate and the Eurasian Plate.
- Urals are very old fold mountains which were formed even before the breakup of Pangaea. They were formed due to collision between Europe and Asia.
- Appalachians are also very old fold mountains which were formed even before the breakup of Pangaea. They were formed due to collision between North America and Europe.

Mains Question on Fold Mountains

Why are the world's fold mountain systems located along the margins of continents? Bring out the association between the global distribution of Fold Mountains and the earthquakes and volcanoes.

Why fold mountains at continental margin?

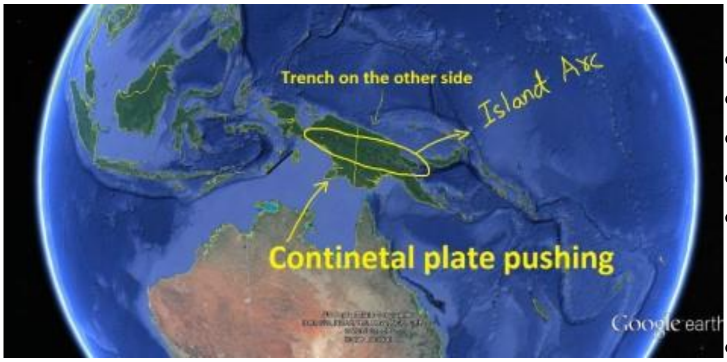
- Fold mountains are formed due to convergence between two continental plates (Himalayas) or between an oceanic and a continental plate (Rockies. Explained in previous post).
- In Continent – Continent (C-C) convergence, oceanic sediments are squeezed and up thrust between the plates and these squeezed sediments appear as fold mountains along the plate margins.

- In Continent – Ocean (C-O) convergence, the continental volcanic arc formed along the continental plate margin is compressed and is uplifted by the colliding oceanic plate giving rise to fold mountains along the continental plate margin.

Association

- In both C-C convergence and C-O convergence, there is formation of fold mountains and frequent occurrence of earthquakes.
- This is because of sudden release of friction between the subducting plate and up thrust plate. In C-C convergence, the denser plate pushes in to the less denser plate creating a fault zone along the margin. Further collision leads to sudden release of energy along this fault zone generating disastrous earthquakes (Himalayan Region).
- In C-O regions the subducting oceanic plate grinds against the surrounding denser medium producing mostly deep focus earthquakes.
- Volcanism is observed only in C-O convergence and is almost absent in C-C convergence. This is because of the thick continental crust in C-C convergence which prevents the outflow of magma. Magma lies stocked within the crust.
- In C-O convergence, metamorphosed sediments and melting of the subducting plate form magma which escapes to the surface through the less thicker continental crust.

Continent – Arc Convergence or New Guinea Convergence



- New Guinea came into being about 20 million years ago as a result of continent – arc collision.
- The continental plate pushes the island arc towards the oceanic crust. The oceanic plate plunges under the island arc.
- A trench occurs on the ocean side of the island arc and, ultimately, the continental margin is firmly welded against the island arc.

In this post we will study about different Types of Mountains which are classified based on various factors.

Orogeny

- **Orogeny (Geology)** is a process in which a section of the earth's crust is **folded** and deformed by **lateral compression** to form a mountain range.
- Orogenic movements are 'Tectonic movements' of the earth which involve the **folding of sediments**, **faulting** and **metamorphism** [*Geology (of rock)* that has undergone transformation by heat, pressure, or other natural agencies].

Formation of Fold Mountains already explained in Continent – Ocean Convergence – Formation of Andes, Rockies and Continent – Continent Convergence: Formation of Himalayas

Types of Mountains - Classification of Mountains

On the basis of location

Continental mountains

Coastal mountains

- the Rockies,
- the Appalachians,
- the Alpine mountain chains,
- the Western Ghats and
- the Eastern Ghats (India);

Inland mountains

- the Vosges and the Black Forest (Europe),

- the Kunlun, Tienshan, Altai mountains of Asia,
- the Urals of Russia, the Aravallis,
- the Himalayas, the Satpura, and the Maikal of India.

Oceanic mountains

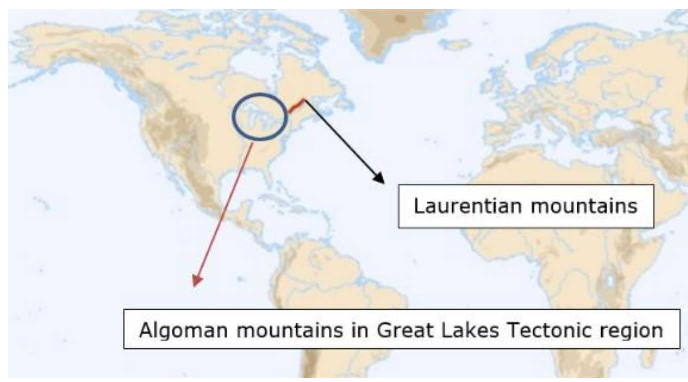
- Oceanic mountains are found on continental shelves and ocean floors.
- If the height of the mountains is considered from the ocean floor, **Mauna Kea (9140)** would be the highest mountain.

On the basis of period of origin

- A total of nine orogenic or mountain building movements have taken place so far.
- Some of them occurred in Pre-Cambrian times between 600-3,500 million years ago.
- The three more recent orogenies are the **Caledonian, Hercynian and Alpine**.

Precambrian mountains

- They belong to the Pre-Cambrian period, a period that extended for more than 4 billion years.
- The rocks have been subjected to upheaval, denudation and metamorphosis. So the remnants appear as **'residual mountains'.**
- Some of the examples are **Laurentian mountains, Algoman mountains** etc..



Caledonian mountains

- They originated due to the great mountain-building movements and associated tectonic movements of the late **Silurian and early Devonian periods**.
- Caledonian mountains came into existence between approximately **430 million years and 380 million years ago**.
- Examples are the **Appalachians, Aravallis, Mahadeo** etc.

Hercynian mountains

- These mountains originated during the upper Carboniferous to Permian Period in Europe.
- Hercynian mountains came into existence between approximately **340 million ears and 225 million** years ago.
- Some examples are the mountains of **Vosges and Black Forest, Altai, Tien Shan mountains of Asia, Ural Mountains etc.**

Alpine system

- Has its origin in the Tertiary Period which consists of the Palaeocene, Eocene, Oligocene, Miocene and Pliocene epochs.
- The mountains were formed from about **65 million years to 7 million years ago.**

Examples are

- **the Rockies of North America, the Alpine mountains of Europe,**
- **the Atlas mountains of north-western Africa,**
- **the Himalayas of the Indian subcontinent in mountains radiating from Pamir knot like Pauntic, Taurus, Elburz, Zagros and Kunlun etc.**

Being the most recently formed, these ranges, such as the Alps, Himalayas, Andes and Rockies are the loftiest with rugged terrain.

On the basis of mode of origin

Original or Tectonic mountains

- Original or Tectonic mountains are the product of tectonic forces.
- The tectonic mountains may be categorized into ***fold mountains*** **(Himalayas, Rockies, Andes etc.),** ***block mountains*** **(Vosges mountains in France, Black Forest in Germany, Vindhya and Satpuras in India etc.) and** ***volcanic mountains*** **(Cascade Range in USA, Mount Kenya, Mount Kilimanjaro, Mount Fujiyama etc.).**

Circum-erosional or Relict or Residual mountains

- Circum-erosional or Relict or Residual mountains (Aravalis in India, Urals in Russia etc.) are the remnants of old fold mountains derived as a result of **denudation** [strip of covering or possessions; make bare].

Based on the formation process

- Fold mountains
- Block mountains
- Volcanic mountains

These will be explained in detail in the next post

Fold Mountains

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

Formation of Fold Mountains was explained previously in Continent – Ocean Convergence – Formation of Andes, Rockies And Continent – Continent Convergence: Formation of Himalayas

- They are the **loftiest** mountains and they are generally concentrated along continental margins.

Fold mountains can be divided into two broad types on the basis of the nature of folds.

Simple fold mountains

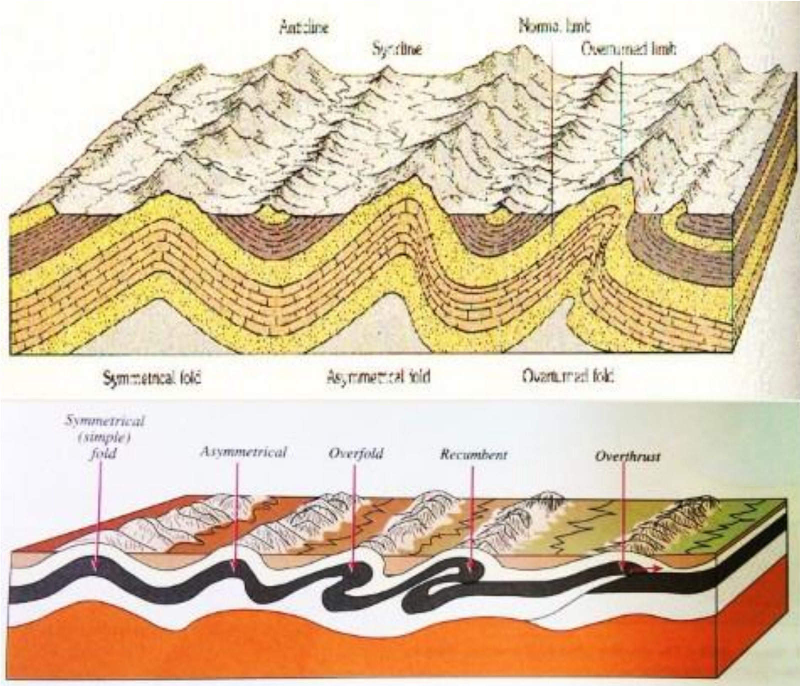
- Simple fold mountains with open folds in which well-developed systems of **synclines** and **anticlines** are found and folds are of wavy patterns.

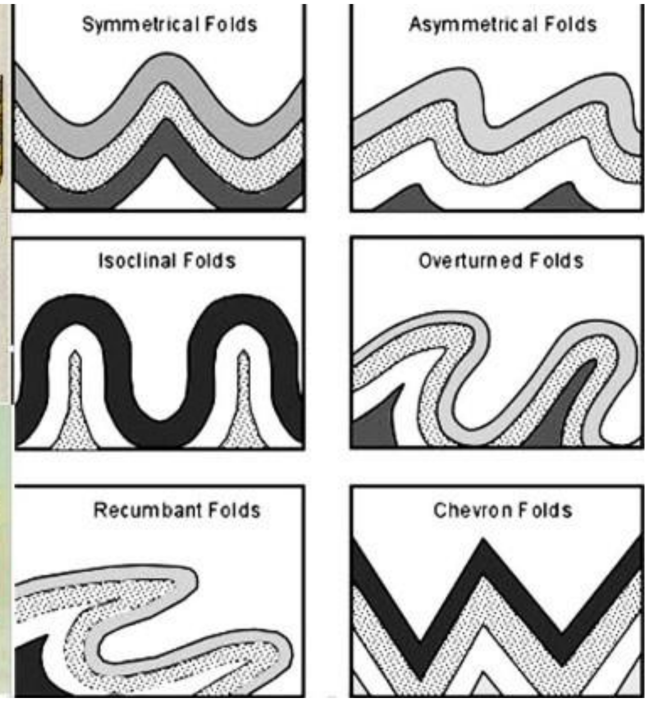
Complex fold mountains

- Complex fold mountains in which the rock strata are intensely compressed to produce a complex structure of folds.

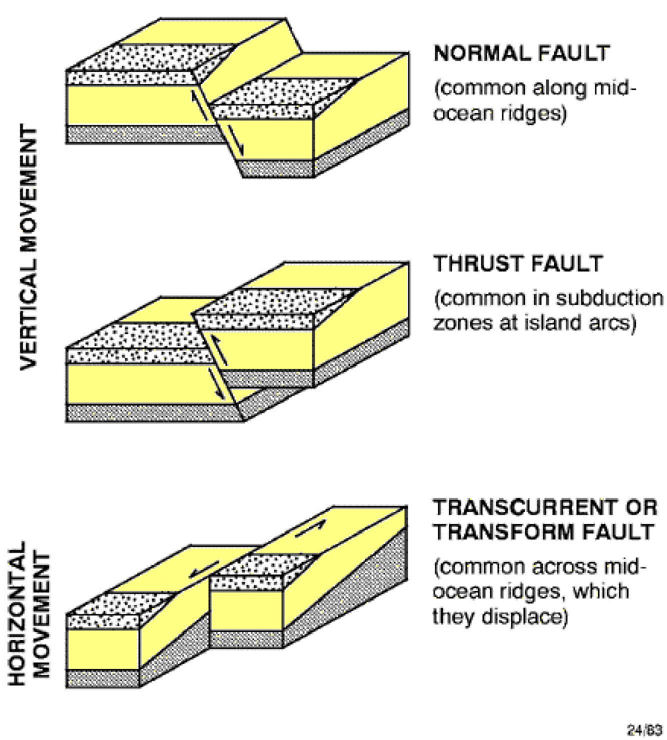
In the Himalayas, **over folds** and **recumbent folds** are often found detached from their roots and carried few hundred kilometres away by the tectonic forces. These detached folds are called **‘nappe’**.

‘Fold’ in geology





‘Fault’ in Geology



On the basis of period of origin, fold mountains are divided into **very old fold mountains, old fold mountains** and **Alpine fold mountains**.

Very Old Fold Mountains

- They are more than 500 million years old.
- Rounded features (due to denudation).
- Low elevation.
- The **Appalachians** in North America and the **Ural mountains** in Russia

Old Fold Mountains

- Old fold mountains had their origin before the Tertiary period (70 million years).
- The fold mountain systems belonging to **Caledonian** and **Hercynian** mountain-building periods fall in this category.
- They are also called as **Thickening relict fold mountains** because of lightly rounded features and medium elevation.
- Top layers worn out due to erosional activity.
- Example: **Aravali Range** in India.
- The **Aravali Range** in India are the **oldest fold mountain systems in India**. The range has considerably worn down due to

the processes of erosion. The range rose in post Precambrian event called the **Aravalli-Delhi orogeny.**

Alpine or young fold mountains

- Alpine fold mountains belonging to the Tertiary period 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

- Rugged relief.
- Imposing height (lofty).
- High Conical Peaks.

Characteristics of Fold Mountains

- Fold mountains belong to the group of **youngest mountains of the earth**.
- The presence of fossils suggest that the sedimentary rocks of these folded mountains were formed after accumulation and consolidation of silts and sediments in a marine environment.
- 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.
- Fold mountains are found along continental margins facing oceans.
- Fold mountains are characterized by **granite intrusions** on a massive scale.
- **Recurrent seismicity** is a common feature in folded mountain belts .
- High heat flow often finds expression in **volcanic activity**.
- These mountains are by far the most widespread and also the most important.
- They also contain rich mineral resources such as **tin, copper, gold** etc..

Some relevant definitions

Ridge

- Mountain ridges refer to mountains which originated as a result of local folding and faulting.
- Generally, the slope of one side of the ridge is steep in contrast to the moderate slope on the other side [In case of Himalayas, the southern slope is steeper compared to the northern slope].
- In some cases a ridge may have a symmetrical slope on both sides.

Mountain range

- It refers to a series of ridges which originated in the same age and underwent the same processes. The most prominent or characteristic feature of mountain ranges is their long and narrow extension.
- Example: Himalayas are a mountain range with Himadri ridge, Himachal ridge and Shiwalik ridge.

Mountain System

- A group of mountain ranges formed in a single period, similar in their form, structure and extension, is termed a mountain system.
- Examples are the Basin Range of Nevada (USA), the Rocky mountain system of North America and the Appalachian.

Mountain Chain

- It consists of mountain ranges which differ in size and periods of formation.

- It refers to highlands composed of different types of mountains viz., fold, block or volcanic mountains although there is a proper arrangement of the mountains.

Cordillera

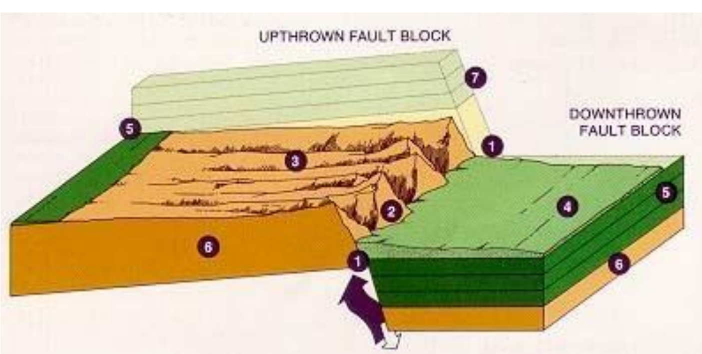
- Cordillera refers to several mountain groups and systems.
- Cordillera is a community of mountains which includes ridges, ranges, mountain chains and mountain systems.
- The best example is the Western Cordillera in the western part of the USA and in British Columbia of Canada.

Block Mountains

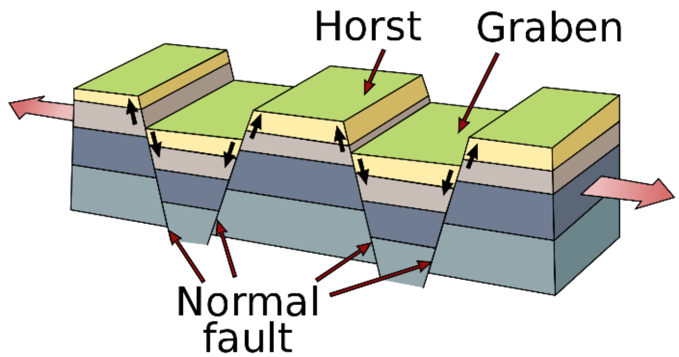
- Block mountains are created when large areas or blocks of earth are broken and **displaced vertically**.
- The uplifted blocks are termed as **horsts** and the lowered blocks are called **graben**.
- The **Great African Rift Valley (valley floor is graben)**, The **Rhine Valley** and the **Vosges mountain** in Europe are examples.
- Block mountains are also called **fault block mountains** since they are formed due to faulting as a result of tensile and compressive forces.
- Block mountains are surrounded by faults on either side of **rift valleys or grabens**.

There are two basic types.

- **Tilted block** mountains have one steep side contrasted by a gentle slope on the other side.



- **Lifted block mountains** have a flat top and extremely steep slopes.



Compression and Tension

- When the earth's crust bends folding occurs, but when it cracks, faulting takes place.
- The faulted edges are very steep, e.g. the Vosges and Black Forest of the Rhineland.
- Tension may also cause the central portion to be let down between two adjacent fault blocks forming a graben or rift valley, which will have steep walls.
- The East African Rift Valley system is the best example. It is 3,000 miles long, stretching from East Africa through the Red Sea to Syria.
- Compressional forces set up by earth movements may produce a thrust or reverse fault and shorten the crust. A block may be raised or lowered in relation to surrounding areas.
- In general large-scale block mountains and rift valleys are due to tension rather than compression.
- The faults may occur in series and be further complicated by tilting and other irregularities.
- Denudation through the ages modifies faulted landforms.

- A majority of geologists argue that block mountains are the product of faulting.
- Sometimes, the surrounding blocks subside leaving the middle block stationary. Such cases are found in high plateau regions.
- Block mountains may originate when the middle block moves downward and becomes a rift valley while the surrounding blocks stand higher as block mountains.

Volcanic mountains

- Volcanic mountains are formed due to volcanic activity.
- Mt.Kilimanjaro in Africa and Mt.Fujiyama in Japan are examples of such mountains.
- These are, in fact, volcanoes which are built up from material ejected from fissures in the earth's crust.
- The materials include molten lava, volcanic bombs, cinders, ashes, dust and liquid mud.
- They fall around the vent in successive layers, building up a characteristic volcanic cone.
- Volcanic mountains are often called mountains of accumulation.
- They are common in the Circum-Pacific belt and include such volcanic peaks as Mt. Fuji (Japan) Mt. Mayon (Philippines), Mt. Merapi (Sumatra) etc.

Residual mountains

- These are mountains evolved by **denudation**.
- Where the general level of the land has been lowered by the agents of denudation some very resistant areas may remain and these form residual mountains, e.g. Mt. Manodnock in U.S.A.
- Residual mountains may also evolve from plateaus which have been dissected by rivers into hills and valleys.
- Examples of dissected plateaux, where the down-cutting streams have eroded the uplands into mountains of denudation, are the Highlands of Scotland, Scandinavia and the Deccan Plateau.

Significance of mountains

- The mountains are a storehouse of water.
- Many rivers have their source in the glaciers in the mountains.
- Water from the mountains is also used for irrigation and generation of hydro-electricity.
- The river valleys and terraces are ideal for cultivation of crops.
- Mountains have a rich variety of flora and fauna.

In this post we will study about **Divergent Boundary** (Divergent plate boundary or **Constructive Edge**). We will study about the important land forms created due to divergent boundary. These important land forms include the **East African Rift System, Rift Lakes, Great Rift System** etc.. We will also study the formation and evolution of **Rift Valley, Linear Sea, Oceans** etc..

Interaction of Plates

- Major geomorphological features such as fold mountains, block mountains, mid-oceanic ridges, trenches, volcanism, earthquakes etc. are a direct consequence of interaction between various lithospheric plates.
- There are three ways in which lithospheric plates interact with each other.

1. **Divergence:** Divergent boundary is also called as **constructive edge**. Mid-oceanic ridges, rift valleys, block mountains, etc. are the common landforms formed due to divergence.
2. **Convergence:** Convergent boundary is also called as **destructive edge**. Fold mountains, trenches, island arcs, continental arcs, etc. are the common landforms formed due to convergence.
3. **Transcurrent boundary or transform edge:** Here the landform is deformed due to the horizontal grinding (plates slide past each other horizontally) of the lithospheric

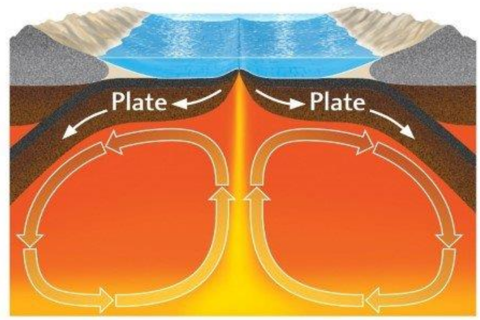
plates. Example: **San Anderas Fault, USA.**

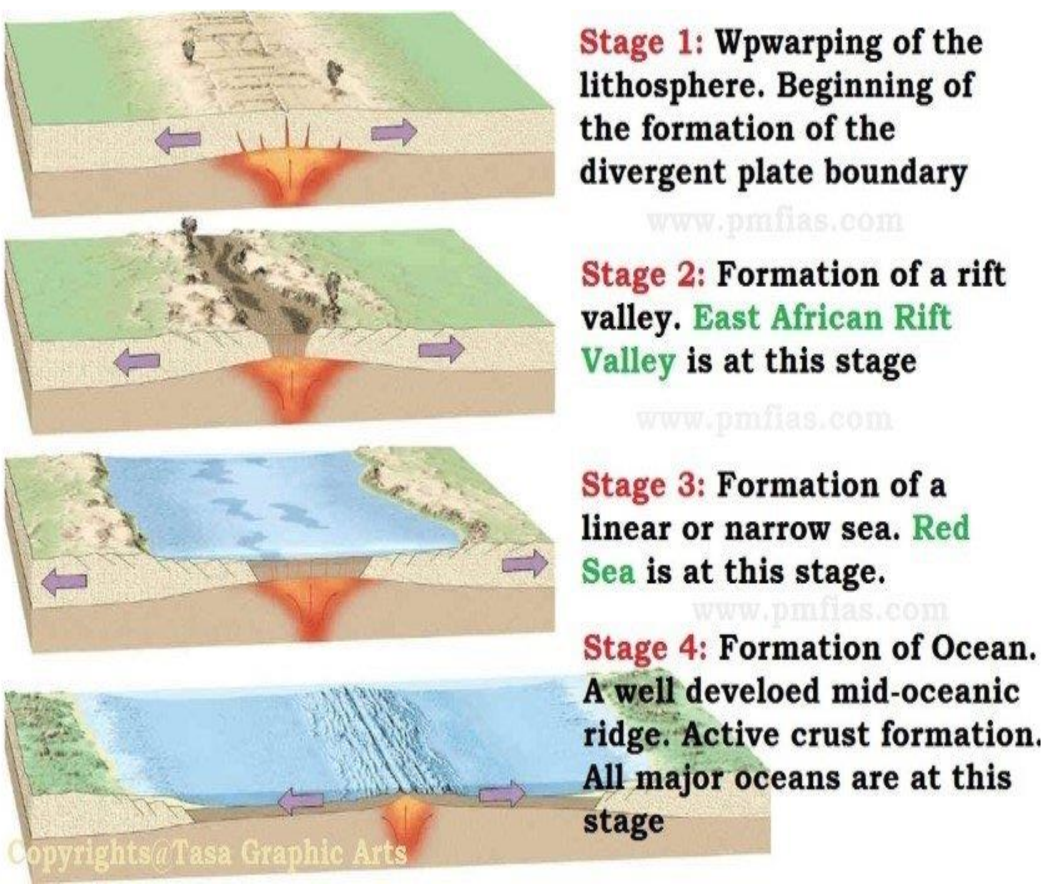
I have already explained about Convergence and types of convergence in these posts:

1. [Ocean – Ocean Convergence – Island Arc Formation]
2. [Continent – Ocean Convergence – Formation of Andes, Rockies]
3. [Continent – Continent Convergence: Formation of Himalayas]

Divergent boundary

- In the See Floor Spreading theory, we have studied how divergent boundaries below the oceans are responsible for the spreading of the see floor. In Plate Tectonics, we have learnt about the major and minor lithospheric plates and how these plates moved thorough the geological past. We have studied about **convection currents** in the mantle which are the primary reason behind plate movements – divergence (divergent boundary) and convergence (convergent boundary) of the lithospheric plates.
- The horizontal limbs of the convection currents, just below the lithosphere, drag the plates horizontally.
- The falling limbs of the convection currents create a negative pressure on the lithosphere and this negative pressure (pulling force) is responsible for the formation the convergent boundary.
- The rising limbs on the other hand create positive pressure on the lithosphere and this positive pressure (pushing force) creates a divergent boundary.





- Divergence (divergent boundary) is responsible for the **evolution and creation of new seas and oceans** just like convergent boundaries are responsible for the formation of fold mountains, volcanic arcs (few exceptions like Hawaii) etc..

Evolution – Formation of Rift Lakes, Seas and Oceans

- The formation of atmosphere and the oceans took millions of years. They were formed due to continuous 'degassing' of the Earth's interior [denser elements settled at the center of the earth and the lighter elements at the surface].
- After the Earth's surface temperature came down below the boiling point of water, rain began to fall.
- Water began to accumulate in the hollows and basins and the primeval [of the earliest time in history] water bodies were formed.
- The primeval water bodies evolved to form seas and oceans.
- The process of formation of a new sea begins with the formation of a divergent boundary.
- **New lithosphere is created at the divergent boundary and old lithosphere is destroyed somewhere else at the convergent boundary**.

Basic Terms

- **Up warp:** *Geology* a broad elevated area of the earth's surface.
- **Plume:** *Geology* a column of magma rising by convection in the earth's mantle.
- **Rift Valley:** A rift valley is a linear-shaped lowland between several highlands or mountain ranges created by the action of a geologic rift or fault.

Stage 1: Upwarping, fault zones

- Rising limbs of the convectional currents create a mantle plume that tries to escape to the surface by upwarping the lithosphere. During upwarping, a series of faults are created. Both normal and thrust faults (reverse fault) occur during upwarping. Divergence of plates begin.

Stage 2: Rift Valley Formation

- Faulting due to divergence creates extensive rift system (fault zones, rift valleys). Rifting is followed by flood basalt volcanism in some places that spread around the rift creating plateaus, highlands etc.. **East African Rift Valley** is at this stage of evolution.

[**Narmada and Tapti Rift Valleys** (fault zones) are formed from a mechanism different from the one explained above. They are formed due to bending of the northern part of the Indian plate during the formation of Himalayas.]

Stage 3: Formation of Linear Sea or Rift Lakes

- Rift valley deepens due to further divergence and makes way for ocean waters. If the rift valleys are formed deeper within the continents, rains waters accumulate forming rift lakes. Rift lakes form some of the largest fresh water lakes on earth.
- Rift valleys evolve into volcanic vent. Block mountains on either side of the rift evolve into oceanic ridges. Successive volcanism and see floor spreading creates spreading sites where new crust is formed (This is the reason that a Divergent Boundary is called a **Constructive Edge**). Oceanic crust starts to replace continental crust. This stage is the formation of linear seas. Example: **Red Sea. Most of the narrow seas are at this stage.**

Stage 4: Linear Sea transforms into Ocean

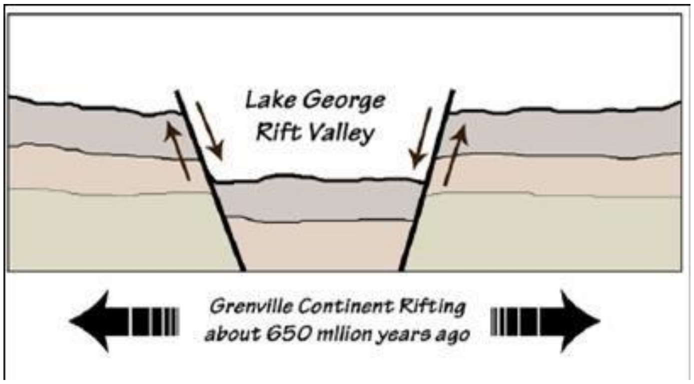
- Intense outpouring of basaltic magma accentuates see floor spreading and oceanic crust formation. Oceanic crust replaces the continental crust and a mighty ocean is formed.
- Crust formation along the mid-oceanic ridge (divergent boundary) is compensated

by crust destruction (crustal shortening) along the convergent boundary **(Destructive Edge).**

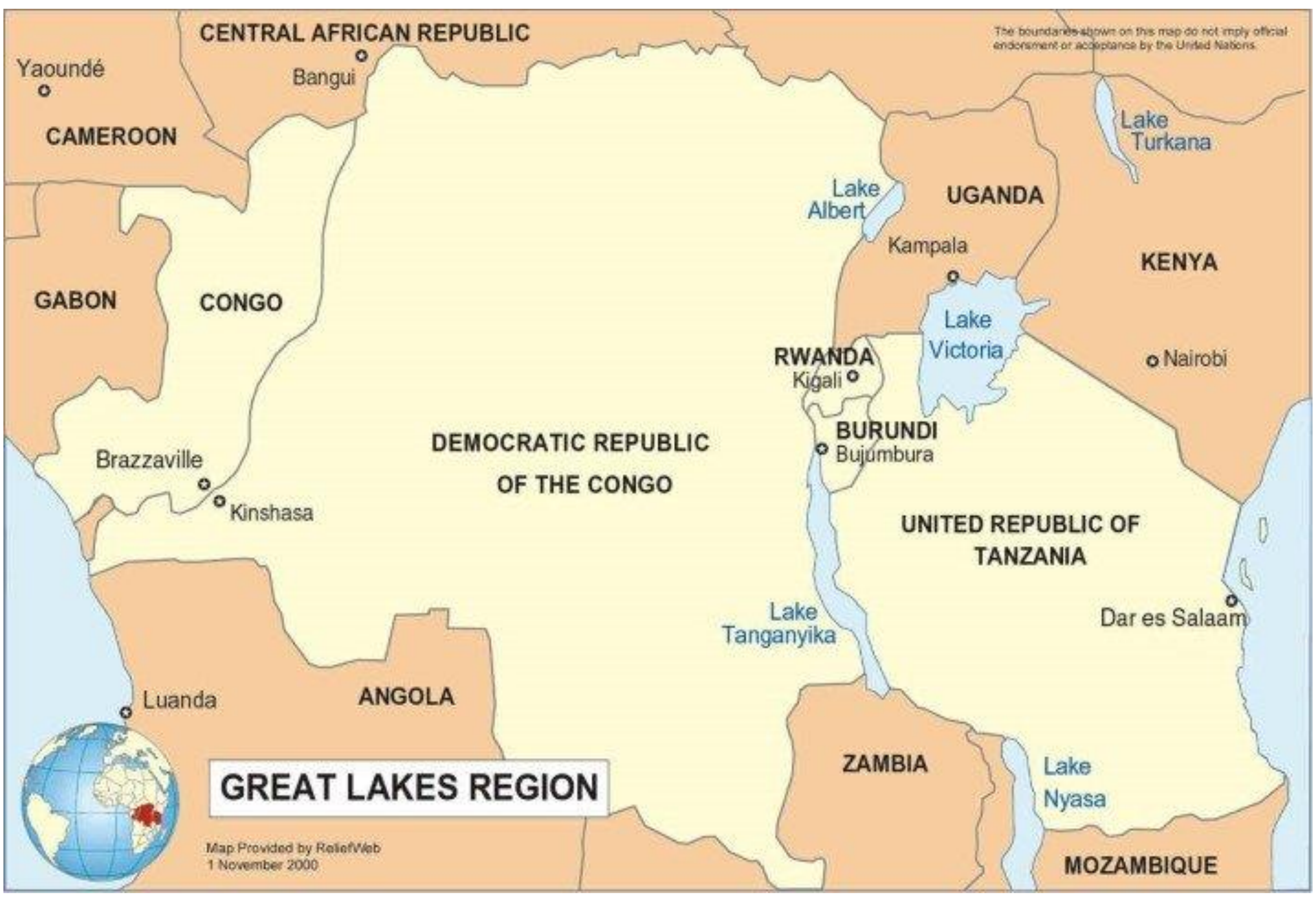
- This is exactly how the continents and oceans get transformed.

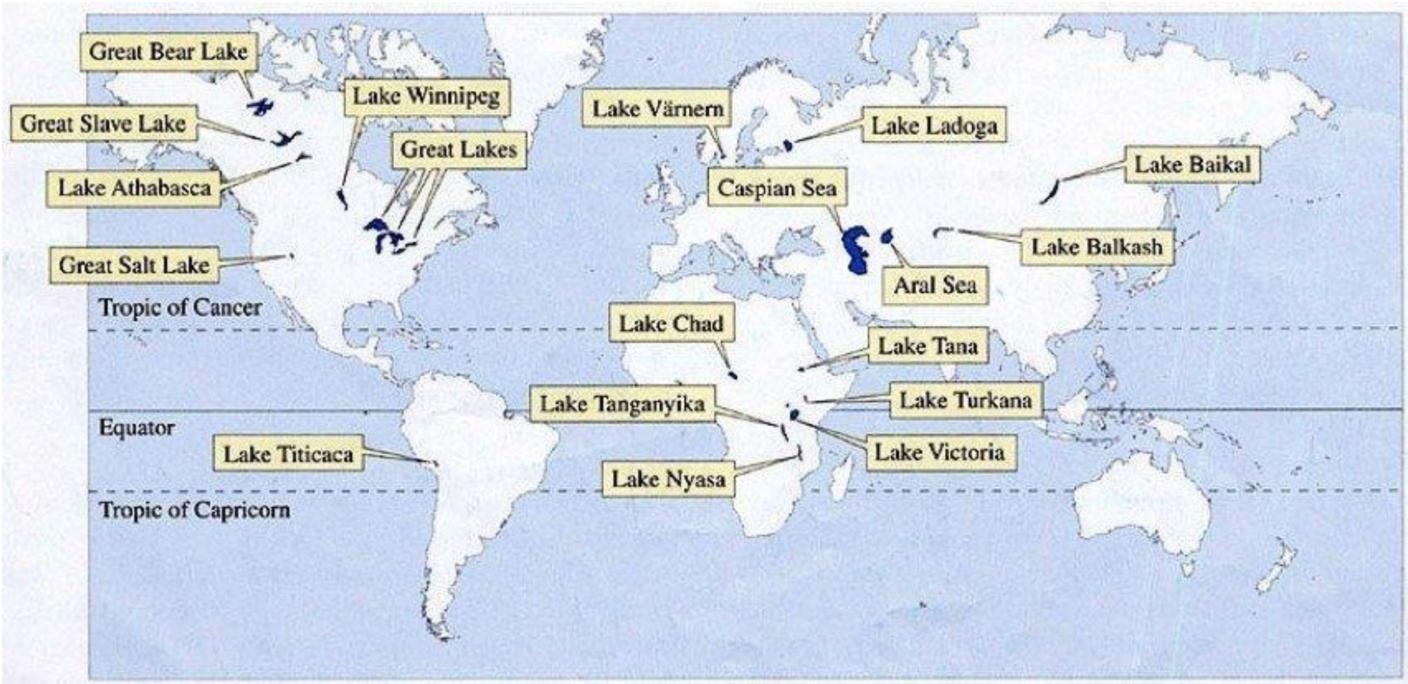
Rift valley lakes

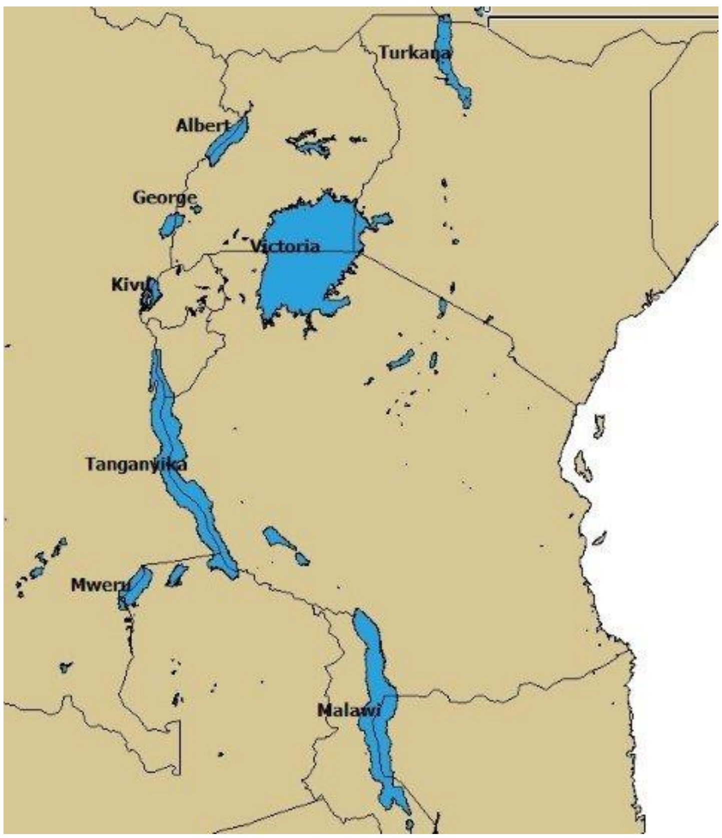
- A rift lake is a lake formed as a result of subsidence related to movement on faults within a rift zone, an area of extensional tectonics in the continental crust.

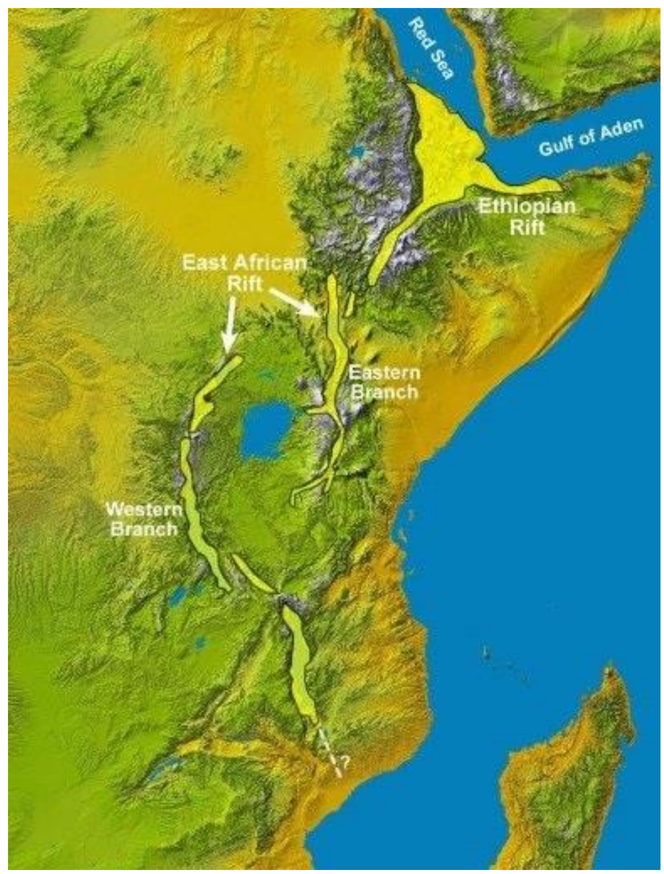


- They are often found within rift valleys and may be very deep. Rift lakes may be bounded by large steep cliffs along the fault margins.
- Many of the world's largest lakes are located in rift valleys.
- **Lake Baikal** in Siberia lies in an active rift valley. Lake Baikal is the **largest (by volume) freshwater lake in the world**, containing roughly 20% of the world's unfrozen surface fresh water.
- **Lake Tanganyika**, **second by both measures**, is in the **Albertine Rift**, the westernmost arm of the active East African Rift.
- Lake Superior in North America, the **largest freshwater lake by area**, lies in the ancient and dormant Midcontinent Rift.





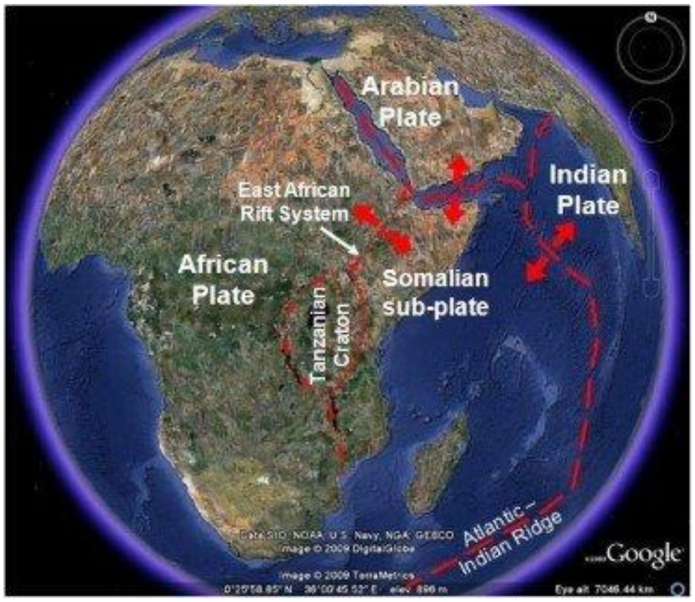




East African Rift Valley

- The East African Rift (EAR) is an active continental rift zone in East Africa.
- The EAR began developing around the onset of the Miocene, **22–25 million years ago**.
- In the past, it was considered to be part of a larger Great Rift Valley.
- The rift is a narrow zone that is a developing divergent tectonic plate boundary, in which the African Plate is in the process of splitting into two tectonic plates, called the **Somali Plate** and the

Nubian Plate (African Plate), at a rate of 6–7 mm annually.



- As extension continues, lithospheric rupture will occur within 10 million years, the Somalian plate will break off, and a new ocean basin will form.

- The Eastern Rift Valley (also known as **Gregory Rift**) includes the Main Ethiopian Rift, running eastward from the Afar Triple Junction, which continues south as the Kenyan Rift Valley.
- The Western Rift Valley includes the **Albertine Rift**, and farther south, the valley of Lake Malawi.
- To the north of the **Afar Triple Junction**, the rift follows one of two paths: west to the **Red Sea Rift** or east to the **Aden Ridge in the Gulf of Aden**.
- The EAR transects through Ethiopia, Kenya, Uganda, Rwanda, Burundi, Zambia, Tanzania, Malawi and Mozambique.
- Prior to rifting, enormous continental flood basalts erupted on the surface and uplift of the **Ethiopian, Somalian, and East African plateaus** occurred.

Volcanism and seismicity along East African Rift Valley

- The East African Rift Zone includes a number of active as well as dormant volcanoes, among them: **Mount Kilimanjaro, Mount Kenya** etc..
- Although most of these mountains lie outside of the rift valley, the EAR created them.
- The EAR is the largest seismically active rift system on Earth today.
- The majority of earthquakes occur near the Afar Depression, with the largest earthquakes typically occurring along or near major border faults.

Great Rift Valley

- The Great Rift Valley is a geographical feature running north to south for around 6,400 kilometers from northern Syria to central Mozambique in East Africa.
- The northernmost part of the Rift forms the Beqaa Valley in **Lebanon**.
- Farther south, the valley is the home of the **Jordan River** which continues south through the Jordan Valley into the **Dead Sea** on the Israeli-Jordanian border.
- From the Dead Sea southward, the Rift is occupied by the **Gulf of Aqaba** and the Red Sea.
- The **Afar Triangle of Ethiopia and Eritrea** is the location of a triple junction.
- The Gulf of Aden is an eastward continuation of the rift and from this point the rift extends southeastward as part of the mid-oceanic ridge of the Indian Ocean.
- In a southwest direction the fault continues as the Great Rift Valley, which split the older **Ethiopian highlands** into two halves.

- In eastern Africa the valley divides into the Eastern Rift and the Western Rift. The Western Rift, also called the **Albertine Rift** contains some of the deepest lakes in the world (up to 1,470 meters deep at Lake Tanganyika).

Transcurrent boundary or transform edge

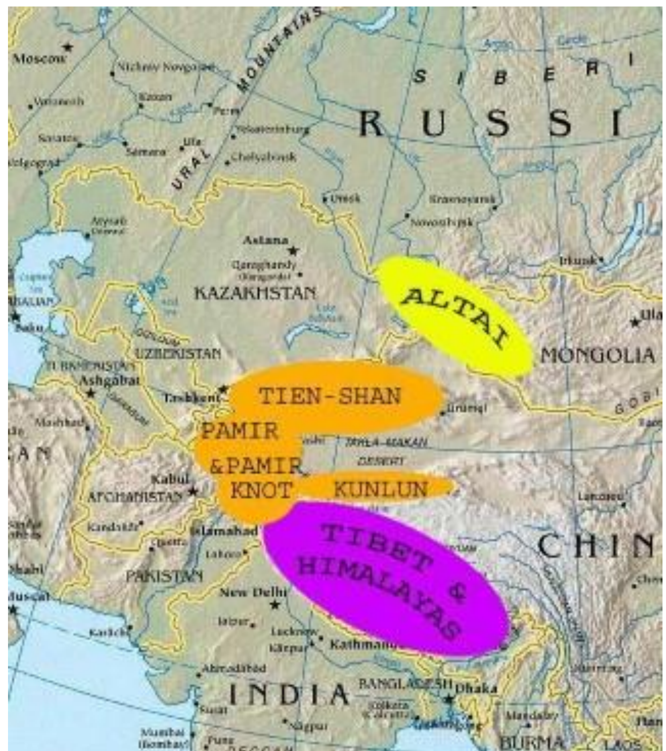
- A transform fault or transform boundary, also known as conservative plate boundary since these faults neither create nor destroy lithosphere.
- Here the movement of the plates is predominantly **horizontal.**
- The effect of a fault is to relieve strain, which can be caused by compression, extension, or lateral stress in the rock layers at the surface or deep in the Earth's subsurface.
- Most transform faults are hidden in the deep oceans. Many transform faults are located on the continental margins as well. The best example is the **San Andreas Fault** on the Pacific coast of the United States.

In this post we will study about some of the most Important Mountain Ranges of the World.

Important mountain ranges

- The highest known mountain on any planet in the Solar System is **Olympus Mons** on **Mars** (~26 km in elevation). It is also the highest active volcano in the Solar System.

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

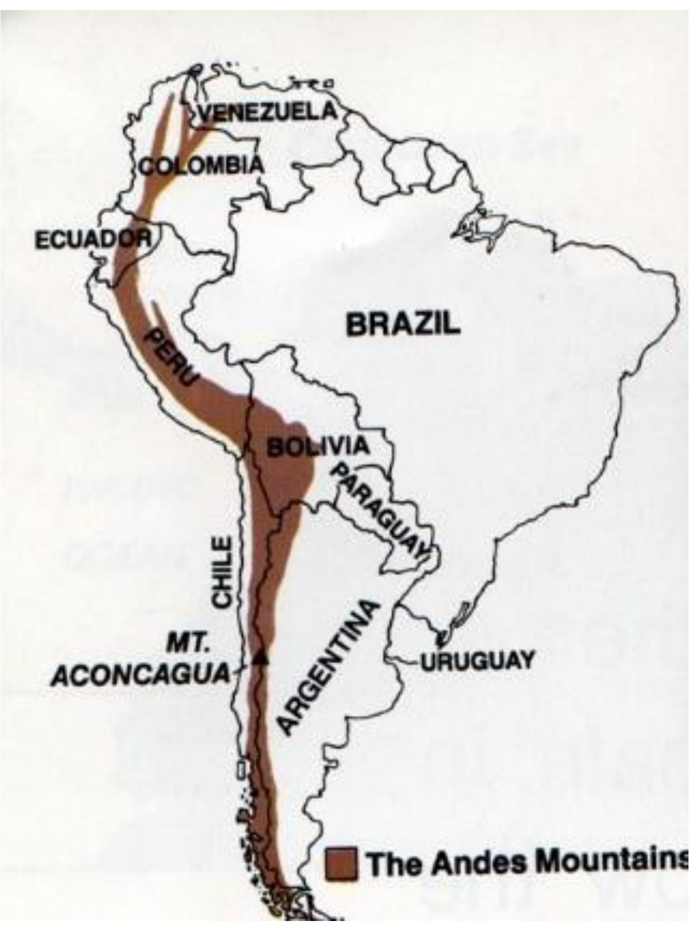


Andes

- The Andes is the **longest** continental mountain range in the world.
- Formed due to Ocean-Continent collision.
- Average height of about 4,000 m.
- Spread along **Venezuela, Colombia, Ecuador, Peru, Bolivia, Chile, and Argentina**.
- The Andes is the world's highest mountain range outside of Asia.
- The highest peak, **Mount Aconcagua**, rises to an elevation of about 6,962 m above sea level
- World's highest volcanoes are in the Andes. **Ojos del Salado** (6,893 m) on the **Chile-Argentina** border is the highest volcano on earth.

Geology

- Caused by the subduction of oceanic crust beneath the South American plate.
- Formed due to compression of western rim of the South American Plate due to the subduction of the **Nazca Plate** and the Antarctic Plate.



Rocky Mountains

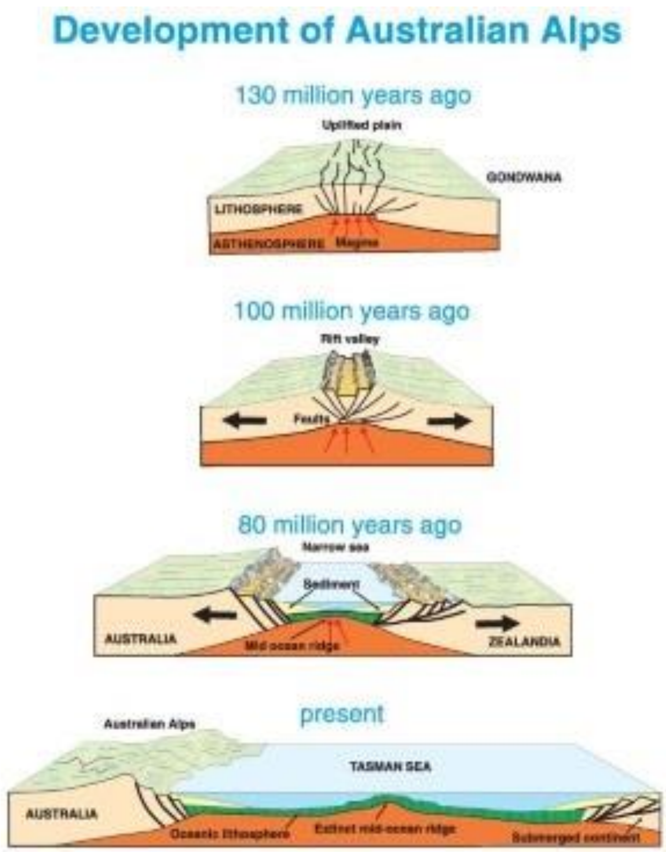
- Mountain range in western North America.
- The Rocky Mountains stretch more than 3,000 miles.
- Spread along northernmost part of British Columbia, in western Canada, to New Mexico, in the southwestern U.S.

Geology of the Rocky Mountains

- Formed due to Ocean - Continent collision.
- The rocks making up the mountains were formed before the mountains were raised.
- The Rocky Mountains took shape during an intense period of plate tectonic activity that resulted in much of the rugged landscape of the western North America.

Great Dividing Range

- The Great Dividing Range, or the Eastern Highlands, is Australia's most substantial mountain range and the third longest land-based range in the world.
- It is also known as the Australian Alps.
- I was formed due to rifting.

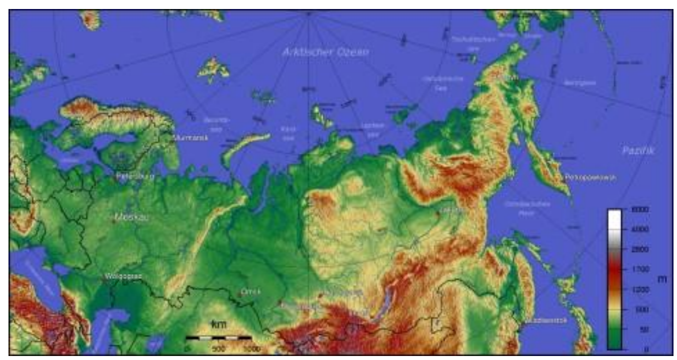


Ural Mountains

- 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.
- Their eastern side is usually considered the natural boundary between Europe and Asia.
- They are rich in various deposits, including metal ores, coal, precious and semi-precious stones.
- Since the 18th century the mountains have been a **major mineral base of Russia**.

Geology

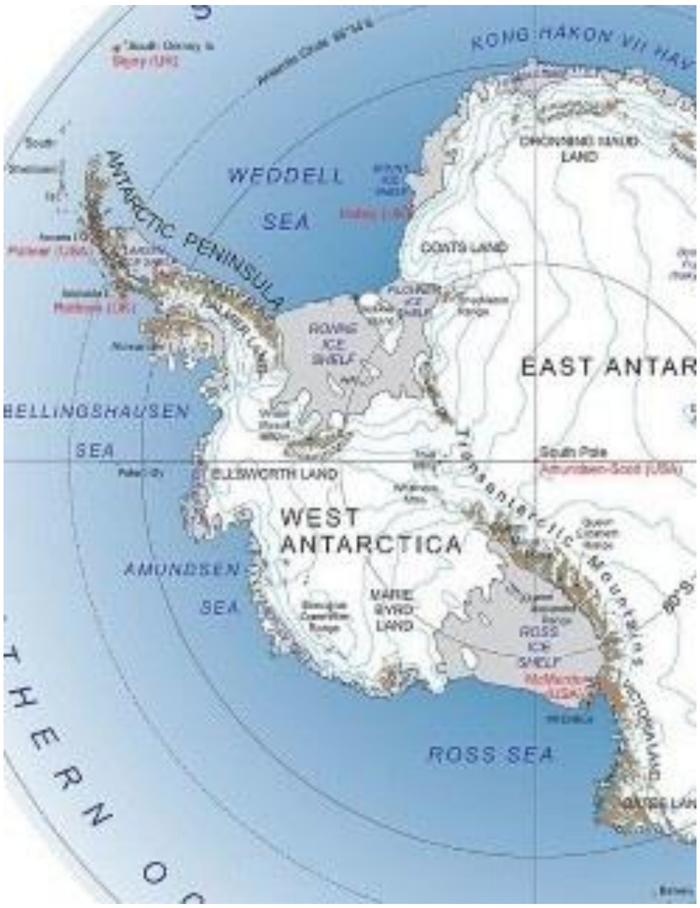
- The Urals are among the world's oldest extant mountain ranges.
- Formed due to **Continent – Continent collision**.
- They were formed during the Uralian orogeny due to the collision of the eastern edge of the supercontinent **Laurussia** with the young and weak continent of **Kazakhstania**, which now underlies much of Kazakhstan. The collision lasted nearly 90 million years in the late Carboniferous – early Triassic.
- Unlike the other major orogens of the Paleozoic (Appalachians, Caledonides), the Urals have not undergone post-orogenic extensional collapse and are unusually well preserved for their age. For its age of 250 to 300 million years, the elevation of the mountains is unusually high.



Atlas Mountains

- Mountain range across the northwestern stretch of Africa extending about 2,500 km (1,600 mi) through **Algeria, Morocco and Tunisia.**
- The highest peak is **Toubkal**, with an elevation of 4,165 metres (13,665 ft) in southwestern Morocco.
- The Atlas ranges separate the Mediterranean and Atlantic coastlines from the Sahara Desert.
- These mountains were formed when Africa and America collided, and were once a chain rivaling today's Himalayas.
- Some remnants can also be found in the later formed Appalachians in North America.

Transantarctic Mountains



Appalachian Mountains

- System of mountains in eastern North America.
- One of the major mineral bases of America.

Himalayas

- They separate the plains of the Indian subcontinent from the Tibetan Plateau.
- The Himalayan range is home to the planet's highest peaks, including the highest, **Mount Everest.**
- By contrast, the highest peak outside Asia – Aconcagua, in the Andes – is 6,961 metres tall.
- The first foothills, reaching about a thousand meters along the northern edge of the plains, are called the **Shiwalik Hills or Sub-Himalayan Range**. Further north is a higher range reaching two to three thousand meters known as the **Lower Himalayan or Himachal or Mahabharat Range**.
- Nepal, Bhutan, India, China, Afghanistan and Pakistan, with the first three countries having sovereignty over most of the range.
- The Himalayas are bordered on the northwest by the **Karakoram** and **Hindu Kush** ranges, on the north by the Tibetan Plateau, and on the south by the Indo-Gangetic Plain.
- Three of the world's major rivers, the Indus, the Ganges and the Tsangpo-Brahmaputra, all rise near **Mount Kailash** and cross and encircle the Himalayas. Their combined drainage basin is home to some 600 million people.
- 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 Tsangpo river.
- The range varies in width from 400 kilometres in the west to 150 kilometres in the east.

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 and the Andaman and Nicobar Islands in the Bay of Bengal were also formed as a result of this collision.
- During the Upper Cretaceous, about 70 million years ago, the north-moving Indo-Australian Plate was moving at about 15 cm per year.
- About 50 million years ago, this fast moving Indo-Australian plate had completely closed the Tethys Ocean, the existence of which has been determined by sedimentary rocks settled on the ocean floor, and the volcanoes that fringed its edges.
- Since both plates were composed of low density continental crust, they were **thrust faulted and folded** into mountain ranges rather than subducting into the mantle along an oceanic trench.
- An often-cited fact used to illustrate this process is that the summit of Mount Everest is made of **marine limestone** from this ancient ocean.
- Today, the Indo-Australian plate continues to be driven horizontally below the Tibetan plateau, which forces the plateau to continue to move upwards.
- The Indo-Australian plate is still moving at 67 mm per year, and over the next 10 million years it will travel about 1,500 km into Asia.
- About 20 mm per year of the India-Asia convergence is absorbed by thrusting along the Himalaya southern front. This leads to the Himalayas rising by about 5 mm per year, making them geologically active.
- The movement of the Indian plate into the Asian plate also makes this region seismically active, leading to earthquakes from time to time.

Hydrology

- The Himalayas have the third largest deposit of ice and snow in the world, after Antarctica and the Arctic. The Himalayan range encompasses about 15,000 glaciers.
- Its glaciers include the **Siachen glacier, Gangotri and Yamunotri** (Uttarakhand) and **Khumbu** glaciers (Mount Everest region), and **Zemu** (Sikkim).

Lakes

- The Himalayan region is dotted with hundreds of lakes. Most lakes are found at altitudes of less than 5,000 m, with the size of the lakes diminishing with altitude.
- **Tilicho Lake** in Nepal in the Annapurna massif is one of the highest lakes in the world.

Impact on climate

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

Alps

- Mountain range systems of Europe stretching approximately 1,200 kilometres and spread across eight Alpine countries from Austria and Slovenia in the east, France, Switzerland, Liechtenstein, and south east Germany, to the west. Monaco and Italy to the south
- The mountains were formed over tens of millions of years as the African and Eurasian tectonic plates collided.
- Extreme shortening caused by the event resulted in marine sedimentary rocks rising by thrusting and folding into high mountain peaks such as **Mont Blanc** and the Matterhorn.
- Mont Blanc spans the French–Italian border, and at 4,810 m is the highest mountain in the Alps.
- The Alpine region area contains about a hundred peaks higher than 4,000 m, known as the "four-thousanders".

- The altitude and size of the range affects the climate in Europe; in the mountains precipitation levels vary greatly and climatic conditions consist of distinct zones.

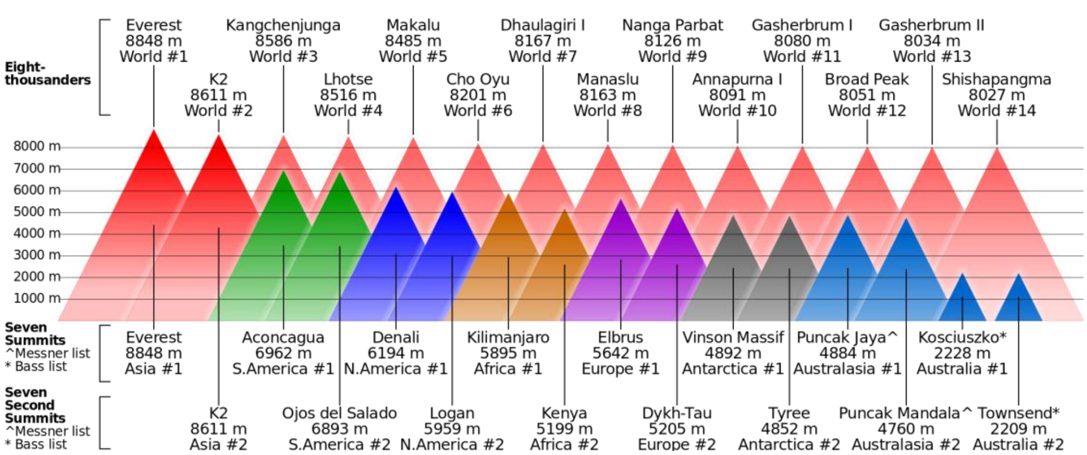
Mountain ranges By height

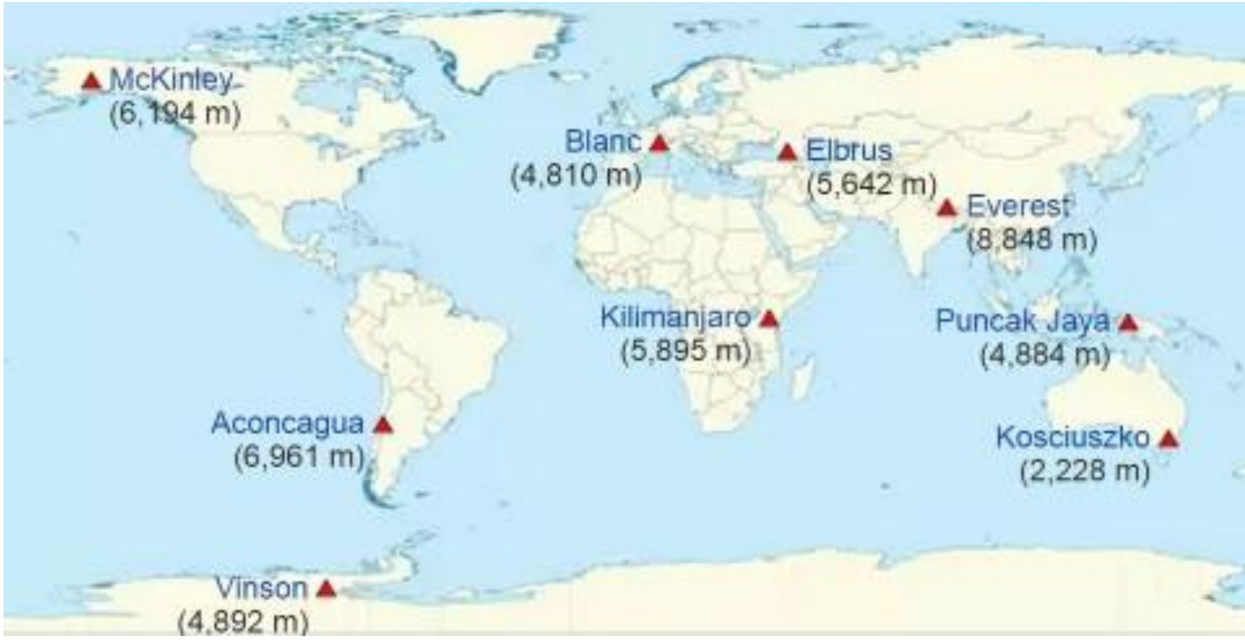
- *Himalayas* - Asia: India, China, Nepal, Pakistan, Bhutan; highest point- Everest; 8848 meters above sea level.
- **Karakoram (part of Greater Himalayas)** - Asia: Pakistan, India, China; highest point- **K2, 8611** meters above sea level.
- **Hindu Kush** - Asia: Afghanistan, Pakistan, India (claim due to Kashmir dispute); highest point- **Tirich Mir, 7708 meters** above sea level.
- Pamir - Asia: Tajikistan, China, Afghanistan, Pakistan, India (claim due to Kashmir dispute); highest point - **Ismail Samani Peak**, 7495 meters above sea level.
- Tian Shan - Asia: China, Kazakhstan, Uzbekistan, Kyrgyztan, India, Pakistan; highest point- Jengish Chokusu, 7439 meters above sea level.

Why are world's highest mountains are at the equator?

- Ice and glacier coverage at lower altitudes in cold climates is more important than collision of tectonic plates. [Glacial erosion is very strong because of huge boulders of rocks carried by the glacial ice that graze the surface. Though ice moves only few meters a day, it can take along it huge rocks that can peal the outer layers.]
- Scientists have solved the mystery of why the world's highest mountains sit near the equator.
- Colder climates are better at eroding peaks. In colder climates, the snowline on mountains starts lower down, and erosion takes place at lower altitudes.
- In general, mountains only rise to around 1,500m above their snow lines, so it is the altitude of these lines — which depends on climate and latitude — which ultimately decides their height.
- 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.

Highest mountain peaks of the world





In this post we will study about Volcanism – Causes and Distribution, Andesitic and Basaltic Lava and Geysers and Hot Water Springs.

Volcanism

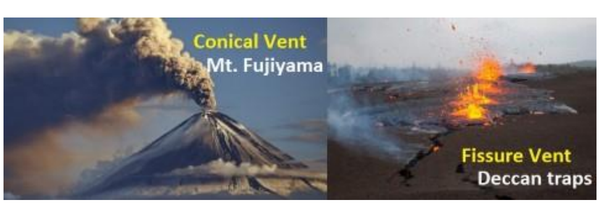
- A volcano is a vent in the earth's crust from which molten rock material (magma), explosive bursts of gases and volcanic ashes erupt..

or

- A mountain or hill having a crater or vent through which lava, rock fragments, hot vapour, and gas are or have been erupted from the earth's crust.

Fissure Vent

- A fissure vent, also known as a volcanic fissure or eruption fissure, is a linear volcanic vent through which lava erupts, **usually without any explosive activity**.
- The vent is often a few meters wide and may be many kilometers long.



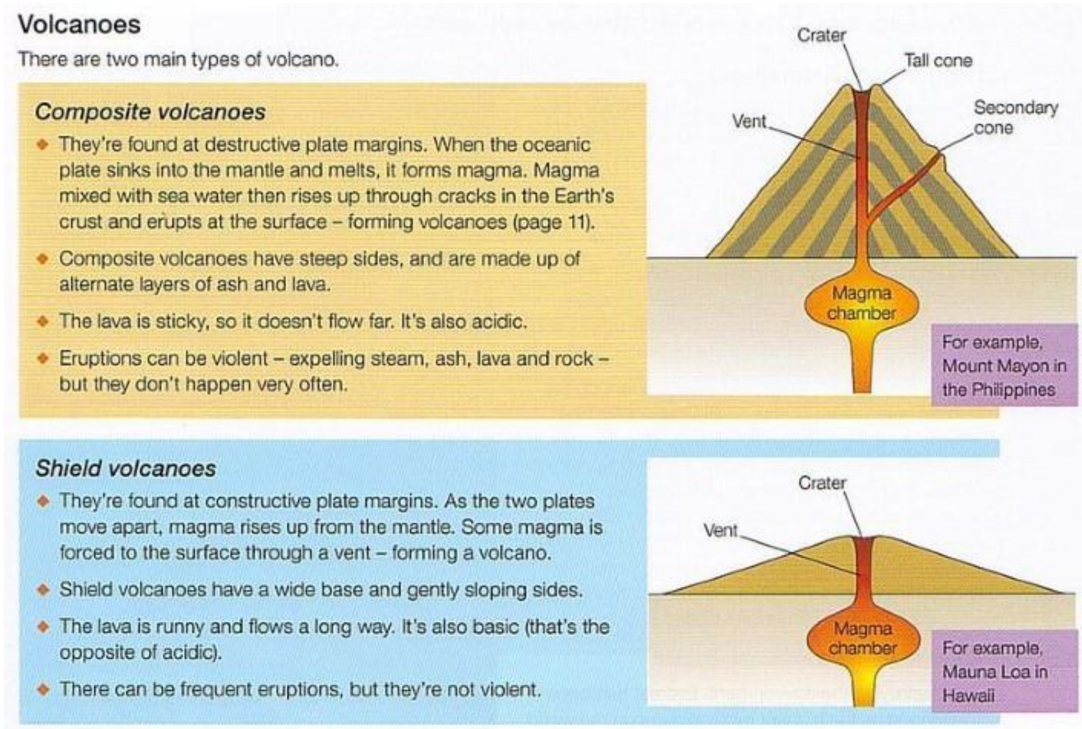
Causes of Volcanism

- The chemical **reactions of radioactive substances** deep within the interior of the earth generate tremendous amount of heat. Some heat is already present in the form of **residual heat** (heat captured at the center during earth's formation) is already present at the earth's interior.
- There is a **huge temperature difference** between the inner layers and the outer layers of the earth due to differential amount of radioactivity. This temperature difference gives rise to **convectional currents** in the outer core as well as the mantle.
- The convectional currents in the mantle create convergent and divergent boundaries.
- At the divergent boundary, molten, semi-molten and sometimes gaseous material appears on earth at the first available opportunity (the best available weak zone – usually a plate margin). The earthquakes may expose fault zones through which magma may escape (This happens in fissure type volcano).
- At the convergent boundary, the subduction of denser plate creates magma at high pressure which will escape to the surface. Because of high pressure, the

magma and gases escape with great velocity as the pressure is released through eruptions.

Volcanism at convergent boundary: [Ocean – Ocean Convergence – Island Arc Formation]

Volcanism at divergent boundary: [Divergent Boundary – African Rift System Formation]



Lava types in Volcanism

Andesitic or Acidic or Composite or Stratovolcanic lava

These lavas are **highly viscous** with a high melting point.

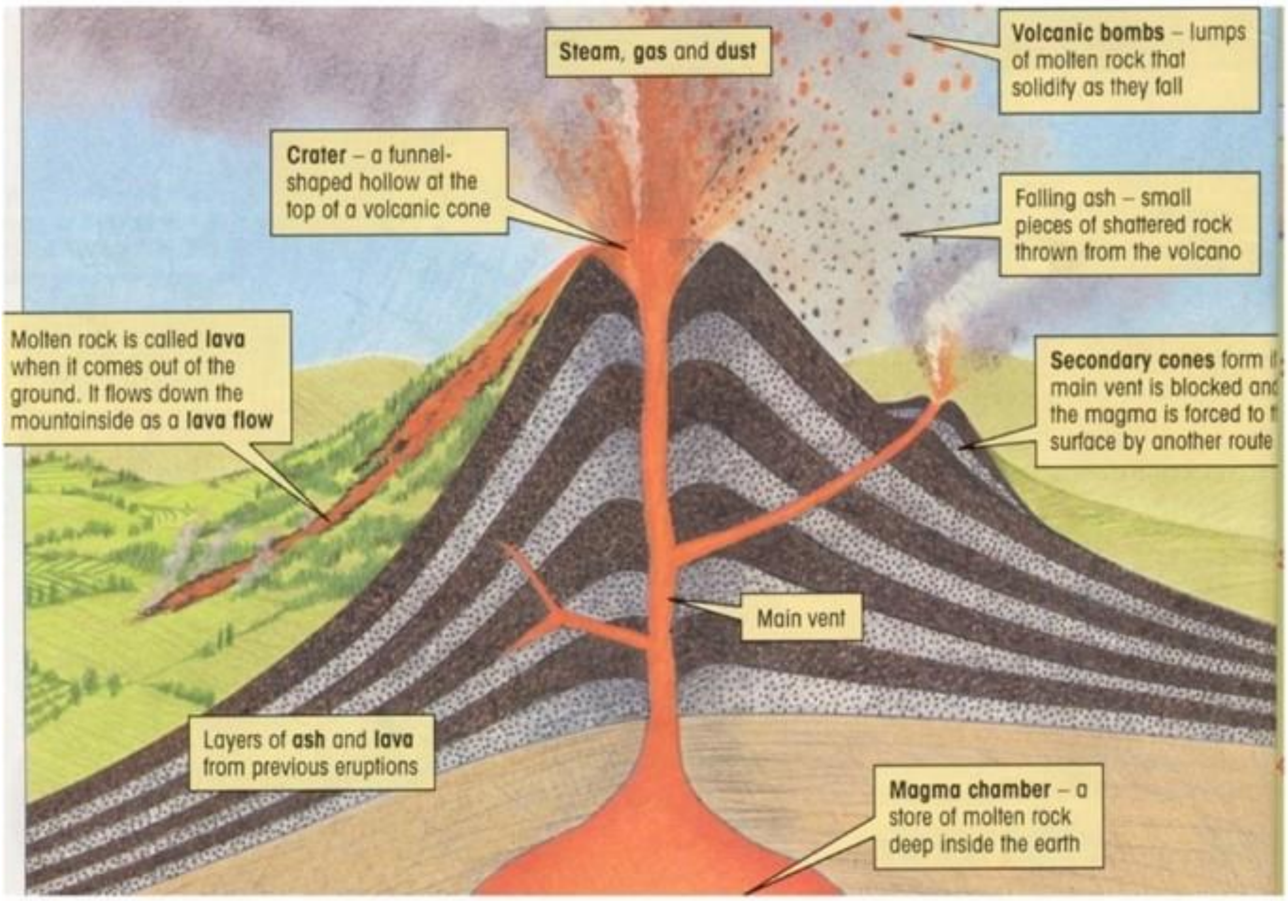
- They are light-colored, of low density, and have a **high percentage of silica**.
- They **flow slowly and seldom travel far** before solidifying. The resultant cone is therefore steep sided.
- The **rapid solidifying of lava** in the vent obstructs the flow of the out-pouring lava, resulting in **loud explosions**, throwing out many volcanic **bombs or pyroclasts**.
- Sometimes the lavas are so viscous that they form a spine or plug at the crater like that of Mt. Pelee in Martinique.

Basic or Basaltic or Shield lava

- These are the hottest lavas, about 1,000°C. (1,830°F.) and are **highly fluid**.
- They are dark colored like basalt, rich in iron and magnesium but **poor in silica**.
- They flow out of volcanic vent **quietly** and are **not very explosive**.
- Due to their **high fluidity**, they flow readily with a speed of 10 to 30 miles per hour.
- They affect extensive areas, spreading out as **thin sheets** over **great distances** before they solidify (This is how **Deccan Traps** were formed).
- The resultant volcano is **gently sloping** with a wide diameter and forms a flattened shield or dome.

Destructive Effects of Volcanoes

- Volcanism can be a greatly damaging natural disaster. The damage is caused by advancing lava which engulfs whole cities.
- Showers of cinders and bombs can cause damage to life.
- Violent earthquakes associated with the volcanic activity and mudflows of volcanic ash saturated by heavy rain can bury nearby places.
- Sometimes ash can precipitate under the influence of rain and completely cover whole cities.
- In coastal areas, seismic sea waves (called tsunamis in Japan) are an additional danger which are generated by submarine earth faults where volcanism is active.

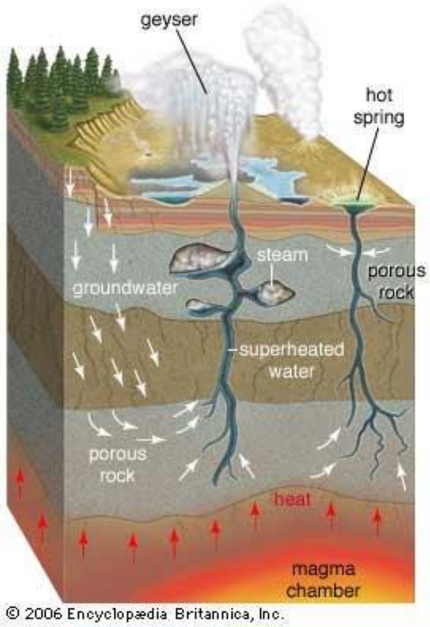


Positive Effects of Volcanoes

- Volcanism creates new landforms like islands, plateaus, volcanic mountains etc.
- The volcanic ash and dust are **very fertile** for farms and orchards.
- Volcanic rocks yield very fertile soil upon weathering and decomposition.
- Although steep volcano slopes prevent extensive agriculture, forestry operations on them provide valuable timber resources.
- Mineral resources, particularly metallic ores are brought to the surface by volcanoes. Sometimes copper and other ores fill the gas-bubble cavities. The famed Kimberlite rock of South Africa, source of diamonds, is the pipe of an ancient volcano.
- In the vicinity of active volcanoes, waters in the depth are heated from contact with hot magma giving rise to **springs and geysers**. The heat from the earth's interior in areas of volcanic activity is used to generate **geothermal electricity**. Countries producing geothermal power include USA, Russia, Japan, Italy, New Zealand and Mexico.
- The **Puga valley in Ladakh** region and **Manikaran (Himachal Pradesh)** are promising spots in India for the generation of geothermal electricity.
- Geothermal potential can also be used for space heating.
- As scenic features of great beauty, attracting a heavy tourist trade, few landforms outrank volcanoes.
- At several places, national parks have been set up, centered around volcanoes.
- As a source of crushed rock for concrete aggregate or railroad ballast, and other engineering purposes, lava rock is often extensively used.

Geysers and Hot Springs

- Almost all the world's geysers are confined to three major areas: **Iceland, New Zealand and Yellowstone Park of U.S.A.**
- Iceland has thousands of hot springs. Some of them have been harnessed to heat houses, swimming pools and for other domestic purposes.



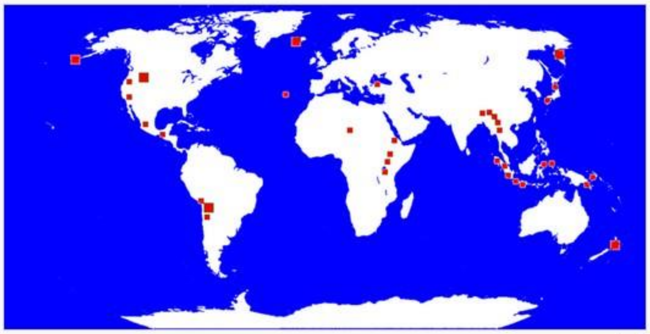
- Hot springs and geysers have become tourist attractions e.g. in Japan and Hawaii.
- Water that percolated into the porus rock is subjected to intense heat by the underlying hard rock which is in contact with hot magma in the mantle or the lower part of crust.
- Under the influence of intense heat the water in the capillaries and narrow roots in the porous rock undergoes intense expansion and gets converted to steam resulting in high pressure.
- When this steam or water at high pressure finds a path to the surface through narrow vents and weak zones, appear at the surface as geysers and hot water springs.

Geyser	**Hot water spring**
Steam or water at high pressure, along its path, gets accumulated in small reservoirs, fissures and fractures. Once the pressure exceeds the threshold limit, the steam bursts out to the surface disrupting the water at the mouth. Hence the name geyser.	Steam or water at high pressure smoothly flows to the top through the vent and condense at the surface giving rise to a spring.
Usually a carter like structure is created at the mouth.	Usually a carter like structure is created at the mouth of the spring.
Silicate deposits at mouth gives them their distinct colours	Some springs are very colorful because of the presence of **cyanobacteria** of different colors.
Found in very few regions. **Iceland** is famous for its geysers.	Found all across the world

1. Steam rises from heated water
2. Pulses of water swell upward
3. Surface is broken
4. Ejected water spouts upward and falls back down into the pipe

Distribution of Volcanoes across the World

- Since the 16th century, around 480 volcanoes have been reported to be active.
- Of these, nearly 400 are located in and around the Pacific Ocean and 80 are in the mid-world belt across the Mediterranean Sea, Alpine-Himalayan belt and in the Atlantic and Indian Oceans.
- The belts of highest concentration are **Aleutian-Kurile islands** arc, **Melanesia** and **New Zealand-Tonga belt**.



Distribution of major geysers in the world.

- Only 10 per cent to 20 per cent of all volcanic activity is above sea and terrestrial volcanic mountains are small when compared to their submarine counterparts.
- Most known volcanic activity and the earthquakes occur **along converging plate margins and mid-oceanic ridges**.
- There is a strikingly close agreement between volcanic and earthquake zones of the earth.

Pacific Ring of Fire

- Circum-Pacilic region, popularly termed the '**Pacific Ring of Fire**', has the greatest concentration of active volcanoes. Volcanic belt and earthquake belt closely overlap along the 'Pacific Ring of Fire'.
- 'Pacific Ring of Fire' is estimated to include **two-thirds** of the world's volcanoes.

Regions with active volcanism along 'Pacific Ring of Fire'

- Aleutian Islands into Kamchatka, Japan,
- the Philippines, and Indonesia (Java and Sumatra in particular),
- Pacific islands of Solomon, New Hebrides, Tonga and North Island, New Zealand.
- Andes to Central America (particularly Guatemala, Costa Rica and Nicaragua), Mexico and right up to Alaska.
- It is said that there are almost 100 active volcanoes in the Philippines, 40 in the Andes, 35 in Japan, and more than 70 in Indonesia.

Along the Atlantic coast

- In contrast, the Atlantic coasts have comparatively few active volcanoes but many dormant or extinct volcanoes, e.g. St. Helena, Cape Verde Islands and Canary Islands etc..
- But the volcanoes of **Iceland** and the **Azores** are active.

Great Rift region

- In Africa some volcanoes are found along the East African Rift Valley, e.g. **Mt. Kilimanjaro** and **Mt. Kenya**, both probably extinct. The only active volcano of West Africa is Mt. Cameroon.
- There are some volcanic cones in Madagascar, but active eruption has not been known so far.

The West Indian islands

- The West Indian islands have experienced some violent explosions in recent times. E.g. **Mt. Pelee**.
- The Lesser Antilles (Part of West Indies Islands) are made up mainly of volcanic islands and some of them still bear signs of volcanic liveliness.

Mediterranean volcanism

- Volcanoes of the Mediterranean region are mainly associated with the Alpine folds, e.g. **Vesuvius**, **Stromboli (Light House of the Mediterranean)** and those of the Aegean islands.
- A few continue into Asia Minor (Mt. Ararat, Mt. Elbruz). The Himalayas have, surprisingly, no active volcano at all.

Why? Know Here: [Continent – Continent Convergence: Formation of Himalayas]

- The volcanism of this broad region, stretching from Spain to the Caucasus, is largely the result of convergence between the Eurasian Plate and the northward-moving African Plate.
- This type of volcanism is mainly due to breaking up of Mediterranean plate into multiple plates due to interaction of African and Eurasian plate

Other regions

- Elsewhere in the interiors of continents—Asia, North America, Europe and Australia, active volcanoes are rare.
- There are **no volcanoes in Australia**.

The Distribution of Earthquakes

- The world's distribution of earthquakes coincides very closely with that of volcanoes.
- Regions of greatest seismicity are Circum-Pacific areas, with the epicentres and the most frequent occurrences along the 'Pacific Ring of Fire.
- It is said that as many as 70 per cent of earthquakes occur in the Circum-Pacific belt.
- Another 20 per cent of earthquakes take place in the Mediterranean-Himalayan belt including Asia Minor, the Himalayas and parts of north-west China.
- Elsewhere, the earth's crust is relatively stable and is less prone to earthquakes, though nowhere can be said to be immune to earth tremors.

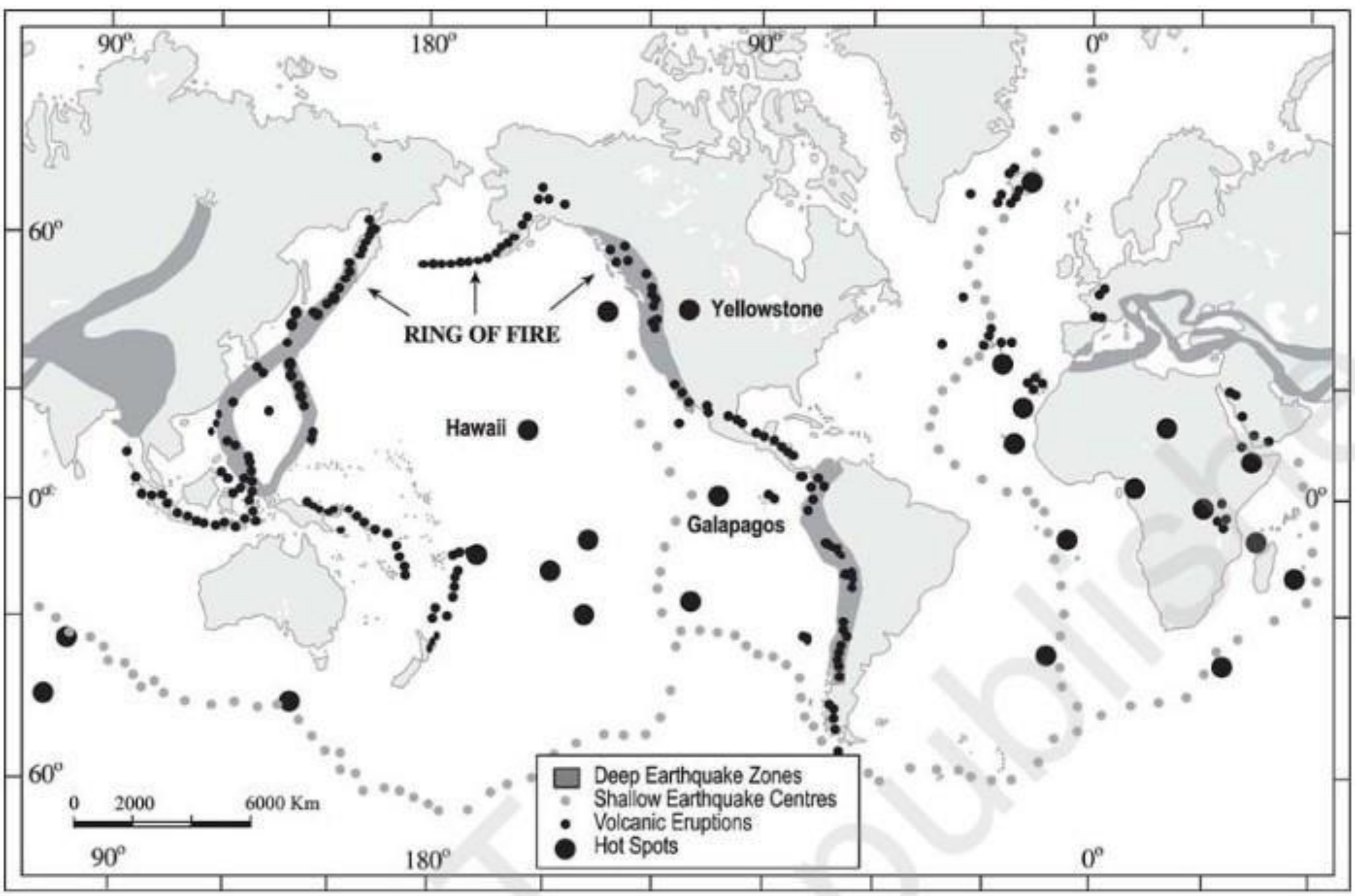


Figure 4. 2 : Distribution of earthquakes and volcanoes

Volcanos in India

- There are **no volcanoes in the Himalayan region** or in the Indian peninsula.

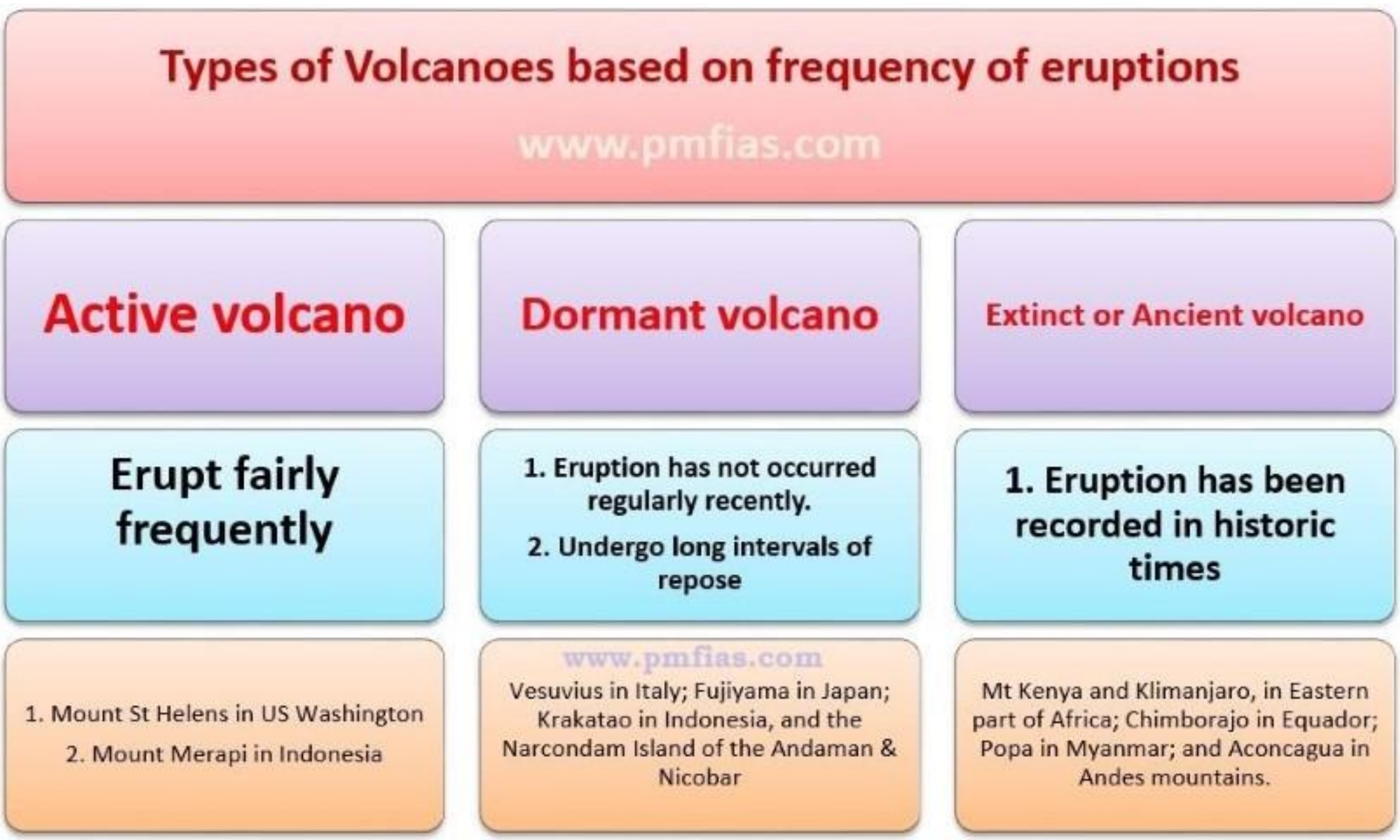
- **Barren Island**, lying 135 km north-east of Port Blair became active again in 1991 and 1995. After its activity in the nineteenth century, it passed through a mild solfataric stage as evidenced by the sublimations of sulphur on the walls of the crater.
- The other volcanic island in Indian territory is **Narcondam**, about 150 km north-east of Barren Island; it is probably extinct. Its crater wall has been completely destroyed.

Extinct, Dormant and Active volcanoes

- 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.**
- The Barren Island in the Andaman and Nicobar Islands of India, Vesuvius (Italy) and Krakatao (Indonesia) which were thought to be extinct, erupted recently and stayed active for few years and are now in dormant stage.
- Krakatao volcano became active in 1883, killing 36,000 people in West Java. Today, Krakatao is no more than a low island with a caldera lake inside its crater.

Some significant Volcanic Eruptions

- In the history of mankind perhaps the most disastrous eruptions were those of **Mt. Vesuvius, Mt. Krakatau and Mt. Pelee.**



Mt. Vesuvius

- Mt. Vesuvius is a Stratovolcano (composite volcano) in Italy.
- Mt. Vesuvius, standing 4,000 feet above the Bay of Naples, erupted violently in A.D. 79.
- The city of Pompeii, located to the south-west, was buried beneath twenty feet of volcanic ashes cemented by the torrential downpours of heavy rain.
- Fertility of the solidified Volcanic ashes tempted many farmers to begin anew on the slopes of Vesuvius.

- Then came the catastrophic eruption of December 1631, ruined fifteen towns and killed inhabitants.

Mt. Krakatau

- The greatest volcanic explosion known to men is perhaps that of Mt. Krakatau in August 1883.
- Krakatau is a small volcanic island in the Sunda Straits, between Java and Sumatra.
- The explosion could be heard in Australia, almost 3,000 miles away.
- Though Krakatau itself was not inhabited and nobody was killed by the lava flows, the vibration set up enormous waves over 100 feet high which drowned 36,000 people in the coastal districts of Indonesia.

Mt. Pelee

- The eruption of Mt. Pelee of the West Indies in May 1902 was the most catastrophic of modem times.
- St. Pierre, the capital of Martinique, lying on the path of the lava, was completely destroyed within minutes.
- Its entire population of 30,000 was killed almost instantly.

Volcanic Landforms

- Volcanic landforms are divided into **extrusive and intrusive landforms** based on weather magma cools within the crust or above the crust.
- Rocks formed by cooling of magma within the crust are called **'Plutonic rocks'.**
- Rocks formed by cooling of lava above the surface are called **'Igneous rocks'.**
- In general, the term 'Igneous rocks' is used to refer all rocks of volcanic origin.

Extrusive Volcanic Landforms

- Extrusive landforms are formed from material thrown out during volcanic activity.
- The materials thrown out during volcanic activity includes lava flows, pyroclastic debris, volcanic bombs, ash and dust and gases such as **nitrogen compounds, sulphur compounds** and minor amounts of **chlorine, hydrogen and argon**.

Conical Vent and Fissure Vent

- A conical vent is a narrow cylindrical vent through which magma flows out violently. Conical vents are common in andesitic (composite or stratovolcano) volcanism.
- A fissure vent, also known as a volcanic fissure or eruption fissure, is a narrow, linear volcanic vent through which lava erupts, usually without any explosive activity. The vent is often a few meters wide and may be many kilometers long. Fissure vents are common in basaltic volcanism.

Mid-Ocean Ridges

- These volcanoes occur in the oceanic areas. There is a system of mid-ocean ridges more than 70,000 km long that stretches through all the ocean basins. The central portion of this ridge experiences frequent eruptions.
- The lava is **basaltic** in nature (Less silica and hence less viscous).
- Cools slowly and flows through longer distances.
- The lava here is responsible for **see floor spreading**.

Composite Type Volcanic Landforms

- They are conical or central type volcanic landforms.
- Along with andesitic lava, large quantities of pyroclastic material and ashes find their way to the ground.
- Andesitic lava along with pyroclastic material accumulates in the vicinity of the vent openings leading to formation of

layers, and this makes the mounts appear as composite volcanoes.

- The highest and most common volcanoes have composite cones.
- They are often called **strato - volcanoes.**
- Mt. **Stromboli 'Lighthouse of the Mediterranean'**, Mt. Vesuvius, Mt. Fuji etc. are examples.

Shield Type Volcanic Landforms

- The **Hawaiian volcanoes** are the most famous examples.
- These volcanoes are mostly made up of basalt, a type of lava that is very fluid when erupted.
- These volcanoes are not steep.
- They become explosive if somehow water gets into the vent; otherwise, they are less explosive.
- Example: Mauna Loa (Hawaii).

Fissure Type Flood Basalt Landforms [Lava Plateaus]

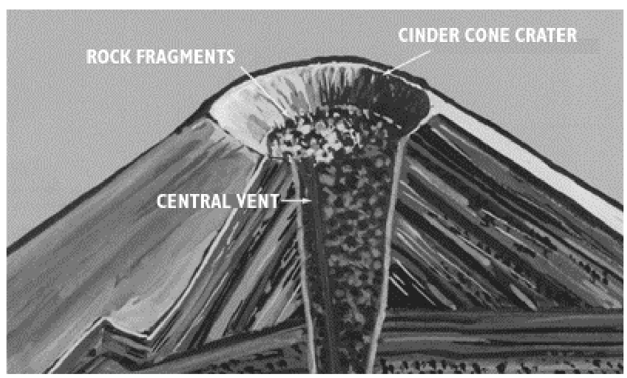
- Sometimes, a very thin magma escapes through cracks and fissures in the earth's surface and flows after intervals for a long time, spreading over a vast area, finally producing a layered, undulating (wave like), flat surface.
- Example: **Deccan traps** (peninsular India), **Snake Basin, U.S.A, Icelandic Shield, Canadian Shield etc..**

Caldera Lake

- After the eruption of magma has ceased, the crater frequently turns into a lake at a later time. This lake is called a 'caldera'. Examples: **Lonar in Maharashtra** and **Krakatao in Indonesia.**

Cinder cone

- A cinder cone is a steep conical hill of loose pyroclastic fragments, such as either volcanic clinkers, cinders, volcanic ash, or scoria that has been built around a volcanic vent.



Intrusive Volcanic Landforms

- Intrusive landforms are formed when magma cools within the crust [**Plutonic rocks (intrusive igneous rock)**].
- The intrusive activity of volcanoes gives rise to various forms.

Batholiths

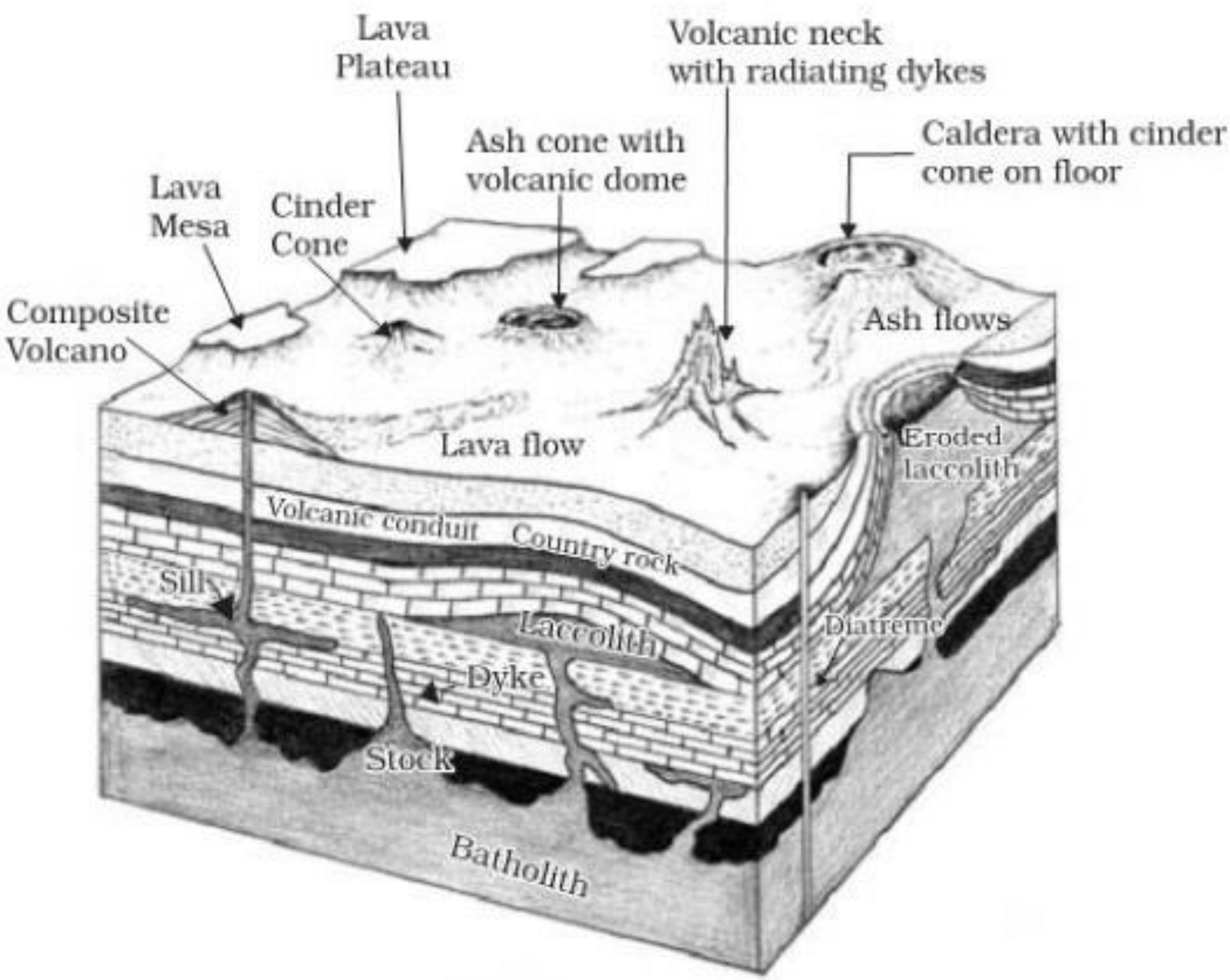
- These are large rock masses formed due to cooling down and solidification of hot magma **inside the earth**.
- They appear on the surface only after the denudation processes remove the overlying materials.
- Batholiths form the core of huge mountains and may be exposed on surface after erosion.
- These are **granitic** bodies.

Laccoliths

- These are large dome-shaped intrusive bodies connected by a pipe-like conduit from below.
- These are basically intrusive counterparts of an exposed domelike batholith.
- The Karnataka plateau is spotted with dome hills of granite rocks. Most of these, now exfoliated, are examples of laccoliths or batholiths.

Lapolith

- As and when the lava moves upwards, a portion of the same may tend to move in a **horizontal** direction wherever it finds a weak plane. It may get rested in different forms. In case it develops into a saucer shape, concave to the sky body, it is called Lapolith.



Phacolith

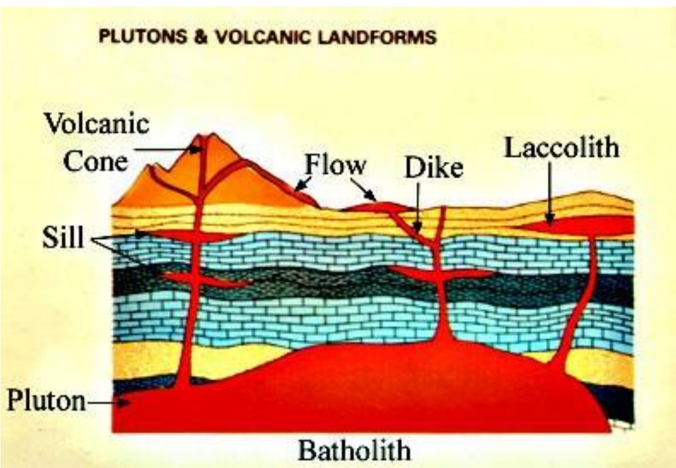
- A wavy mass of intrusive rocks, at times, is found at the base of synclines or at the top of anticline in folded igneous country.
- Such wavy materials have a definite conduit to source beneath in the form of magma chambers (subsequently developed as batholiths). These are called the Phacoliths.

Sills

- These are solidified horizontal lava layers inside the earth.
- The near horizontal bodies of the intrusive igneous rocks are called sill or sheet, depending on the thickness of the material.
- The thinner ones are called sheets while the thick horizontal deposits are called sills.

Dykes

- When the lava makes its way through cracks and the fissures developed in the land, it solidifies almost perpendicular to the ground.
- It gets cooled in the same position to develop a wall-like structure. Such structures are called dykes.
- These are the most commonly found intrusive forms in the western Maharashtra area. These are considered the feeders for the eruptions that led to the development of the Deccan traps.



In this post we will study about **Volcanism Types – Exhalative, Effusive, Explosive and Subaqueous Volcanism.**

- Basically, four types of volcanism can be identified.

1. **Exhalative (vapor or fumes)**
2. **Effusive (Lava outpouring)**
3. **Explosive (Violent ejection solid material)**
4. **Subaqueous Volcanism**

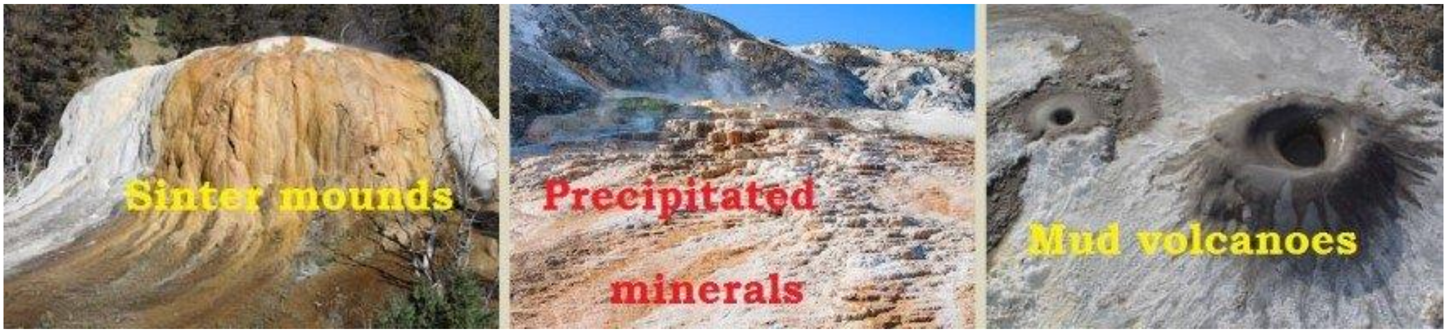
Exhalative (vapor or fumes)

This includes the discharge of material in **gaseous form**, such as

- **steam, fumes and**
- **Hydrochloric acid**
- **Ammonium chloride**
- **Sulphur dioxide**
- **Carbon dioxide**
- **Carbon monoxide.**
- **Hydrogen sulphide**
- **Hydrogen**
- **Nitrogen**

- These gases may escape through vents which are in the form of **hot springs, geysers, fumaroles and solfataras.**
- This kind of volcanism indicates the volcano is reaching its **extinction.**

- Associated landforms ==> sinter mounds, cones of precipitated minerals and mud volcanoes.



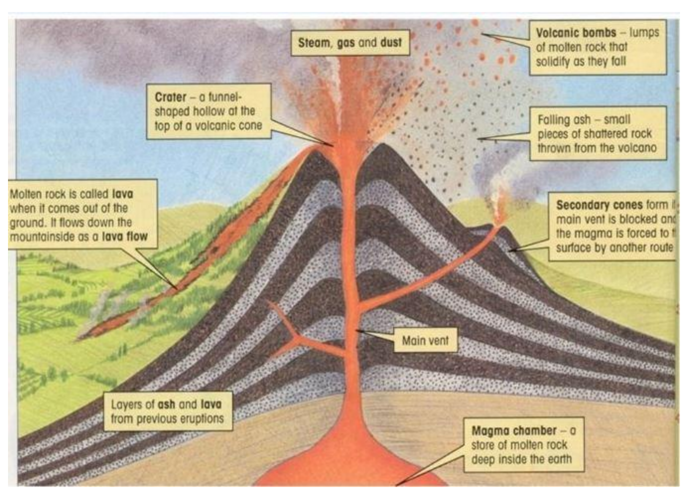
Effusive (Lava outpouring)

- Effusive: *Geology* relating to or denoting igneous rocks poured out as lava and later solidified.
- This type of activity refers to **abundant outpourings of lava from a vent or fissure**.
- Lava is silica poor basic one like **basalt**. Hence flows through larger distances.

- The **Deccan traps**, which are composed of such lavas today, cover an area of 5,00,000 square km. The original extent of the formation must have been at least 14 lakh square km.
- Columnar structure is sometimes developed in fine-grained plateau basalts.
- Columnar basalts are seen in the Deccan traps near Bombay.

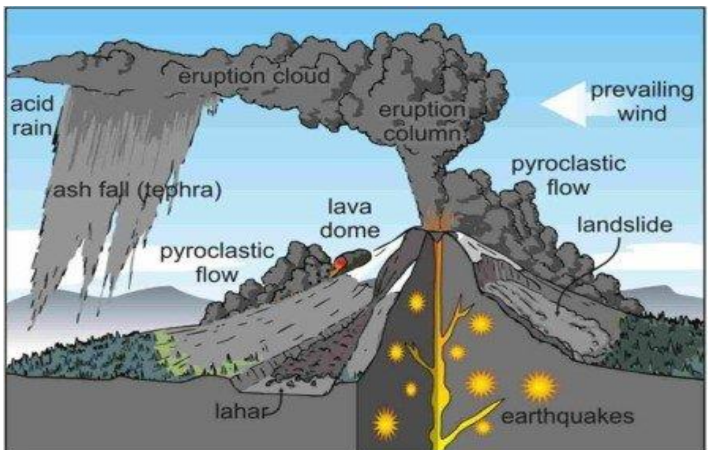
Explosive (Violent ejection of solid material)

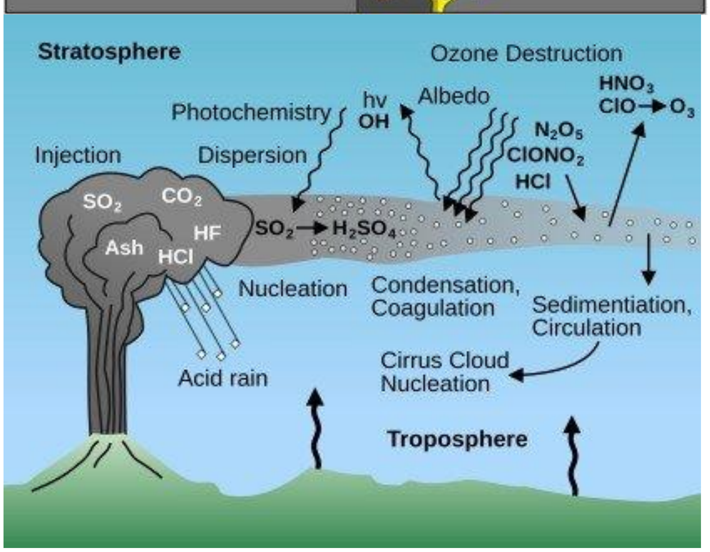
- This type of activity results in fragmentation and ejection of solid material through vents.
- Volcanic eject that settle out of air or water are sometimes called pyroclastic sediments.
- **Tephra:** all fragmented ejects from the volcanoes.
- **Ash:** The finest sand-sized tephra
- **Lappilli:** These are gravel sized particles either in molten or solid state.
- **Blocks:** Cobble or boulder-sized solid ejecta.
- **Bombs:** a lump of lava thrown out by a volcano.
- **Tuff:** Layers of volcanic dust and ashes
- Smaller particles like lapilli and ash travel through air for many kilometres and may remain suspended in the air for a long time.
- The heavier particles like bombs and blocks fall only as far from the vent or fissure as the explosive force is able to hurl them.



Volcanism – Acid Rain, Ozone Destruction

- The volcanic gases that pose the greatest potential hazard to people, animals, agriculture, and property are **sulfur dioxide, carbon dioxide, and hydrogen fluoride etc.**.
- Locally, sulfur dioxide gas can lead to acid rain and air pollution downwind from a volcano.
- Globally, large explosive eruptions that inject a tremendous volume of sulfur aerosols into the stratosphere can lead to lower surface temperatures and promote depletion of the Earth's ozone layer.





Subaqueous Volcanism

- This type of volcanic activity takes places **below the surface of water**.
- When lava flows over the deep ocean floor or is otherwise in contact with water, it

consolidates to produce a structure like that of a heap of pillows
- Pillow lava of Pre-Cambrian Age are found in parts of Karnataka.
- Highly viscous lavas erupted at lesser depths develop glassy margins on pillows. The related volcanic product is hyaloclastite. Most hyaloclastites identified are in Iceland.

Eruptive Volcanism Types

- Based on the typical pattern or mode of eruptions:

Hawaiian Eruption or Icelandic Eruption

- It involves the effusive outpouring of **basalt lava** from craters, lava lakes or fissures.
- A single flow spreads widely over open slopes or flows down the valleys as lava rivers.
- Little gas or tephra is produced.
- Examples: The great basalt plateaus of Columbia and Iceland.

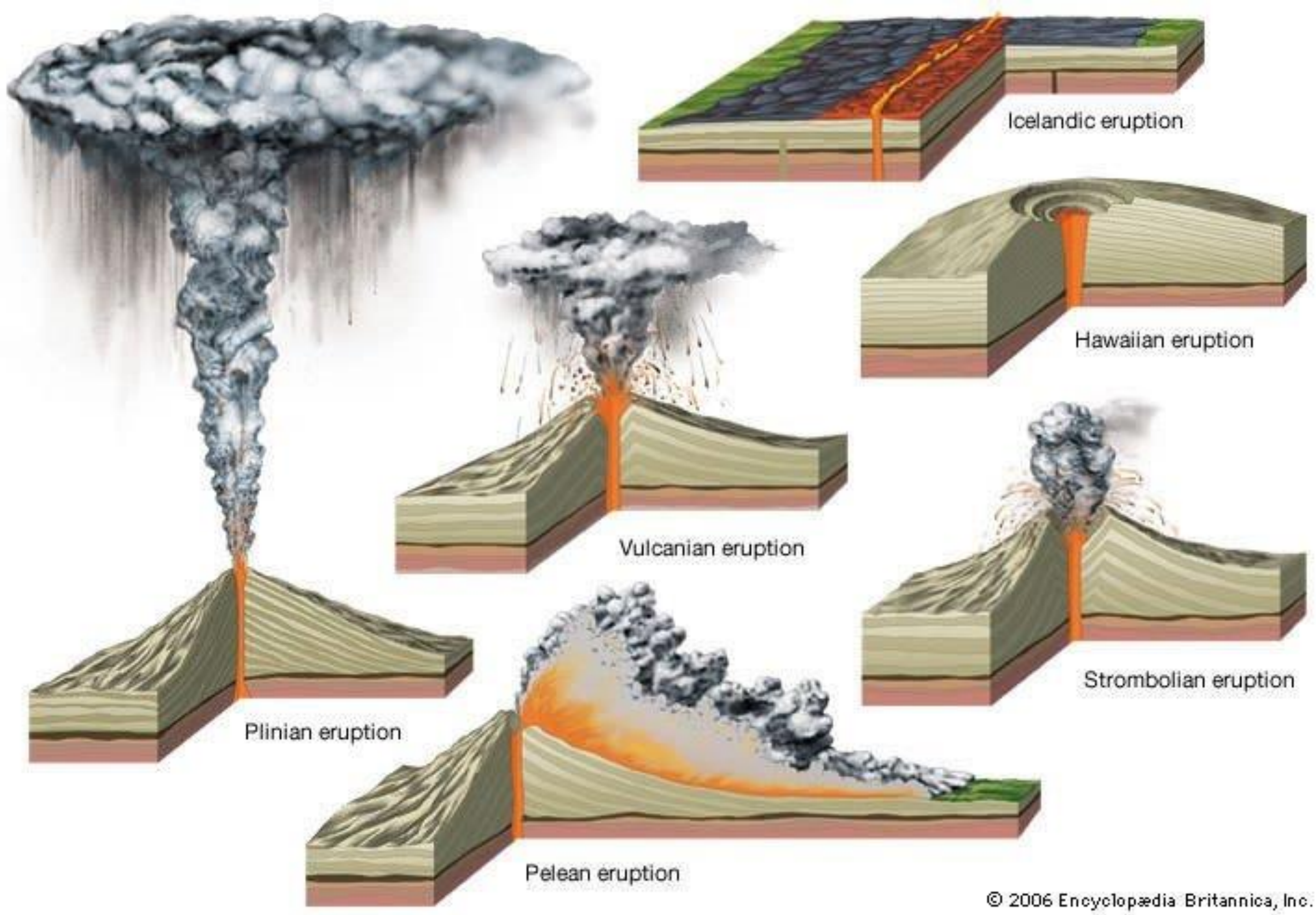
Strombolian Eruption

- In this case, more viscous lava is ejected upward in a fountain like fashion from a lava lake in the crater at regular intervals of around 15 minutes.
- Stromboli lies in the Lipari Islands near Italy.
- It is called the **'lighthouse of the Mediterranean'.**

Vulcanian Eruption

- The eruption in this mode is **explosive.**

- The molten lava which fills the crater solidifies and is explosively ejected as a great cauliflower cloud of dark tephra.
- Bombs, blocks, lapilli and other ejecta fall in the surrounding area.
- Only minor lava flows result.
- After each eruption cycle, the volcano is dormant for decades or for centuries.



Pelean Eruption

- This type of eruption is the result of very viscous, gas-rich, acidic lava flowing violently over the crater rim or breaking out laterally.
- Hot gas and lava mixture is not carried skyward to become cold tephra but spreads downslope as a **nuce ardente**, continuing to evolve gas that cushions the flowing fragments.

Icelandic volcano

- The Icelandic type is characterized by effusions of molten basaltic lava that flow from long, parallel fissures. Such outpourings often build lava plateaus.

In this post we will study about Hotspot Volcanism. Understanding Hotspot volcanism is important to understand the Formation of Hawaiian Islands and Islands of Indian Ocean such as the Lakshadweep islands, Reunion islands, Chagos archipelago etc.

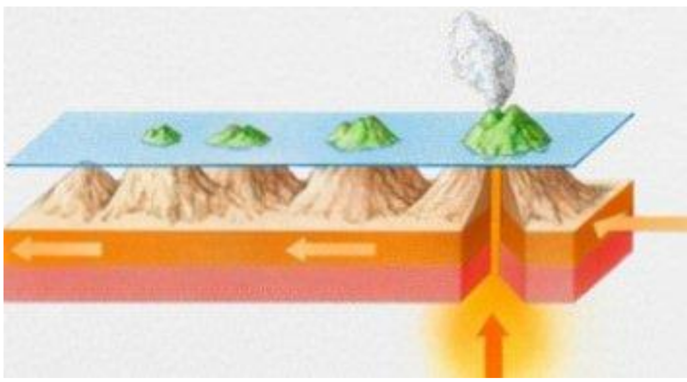
Hotspot Volcanism

- In the previous posts, we have studied about volcanism at convergent and divergent boundaries.
- Hotspot Volcanism is somewhat different from the other types because this type of volcanism occurs not at the margins but at the interior parts of the lithospheric plates.

- Well known examples include **Hawaiian Hotspot Volcanism, Yellowstone Hotspot Volcanism and Reunion Hotspot Volcanism**.

Hot spot

- A hot spot is a region within the Earth's mantle from which heat rises through the process of convection.
- This heat facilitates the melting of rock at the base of the lithosphere, where the brittle, upper portion of the mantle meets the Earth's crust.
- The melted rock, known as magma, often pushes through cracks in the crust to form volcanoes.



Mantle plumes

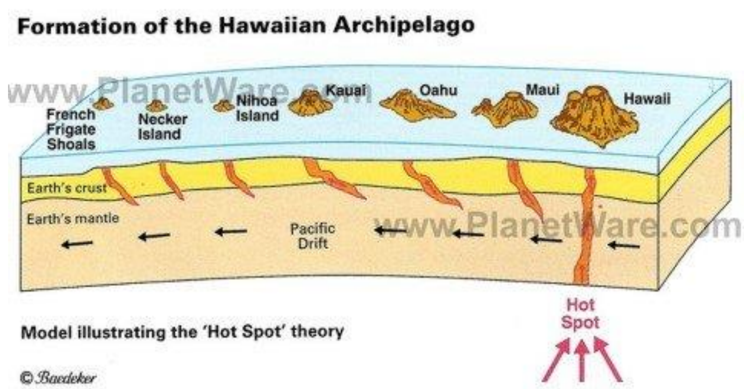
- Hot spot volcanism is unique because it does not occur at the boundaries of Earth's tectonic plates, where all other volcanism occurs.
- Instead it occurs at abnormally hot centers known as mantle plumes. Mantle plumes are exceptionally hot areas fixed deep below the Earth's crust.

Hotspot volcano chain

- A volcano above a hot spot does not erupt forever. Attached to the tectonic plate below, the volcano moves and is eventually cut off from the hot spot.
- Without any source of heat, the volcano becomes extinct and cools. This cooling causes the rock of the volcano and the tectonic plate to become more dense.
- Over time, the dense rock **sinks and erodes**. A new and active volcano develops over the hot spot creating a continuous cycle of volcanism, forming a **volcanic arc**.

Hotspot volcanic landforms

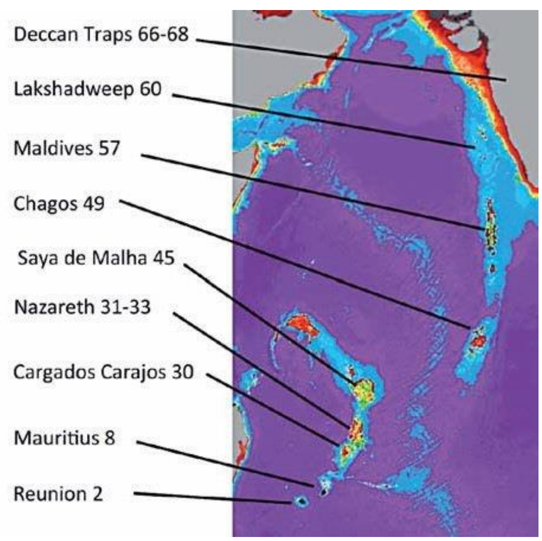
- Volcanic activity at hot spots can create submarine mountains known as **seamounts.**
- Hot spot seamounts that reach the surface of the water can create entire chains of islands, such as the U.S. state of Hawaii.
- **Reunion islands near Madagascar** is also an example of volcanic hotspot.
- Hot spots can also develop beneath continents. The Yellowstone hot spot, for example, has produced a series of volcanic features that extend in a northeastern direction.

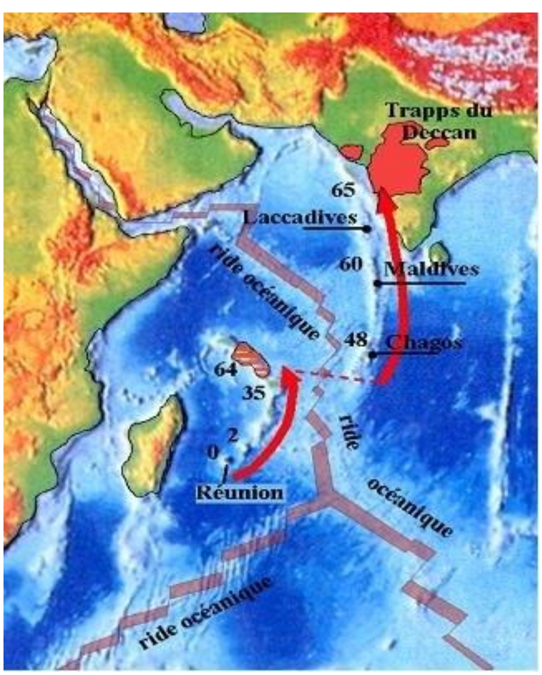


Reunion Hotspot Volcanism

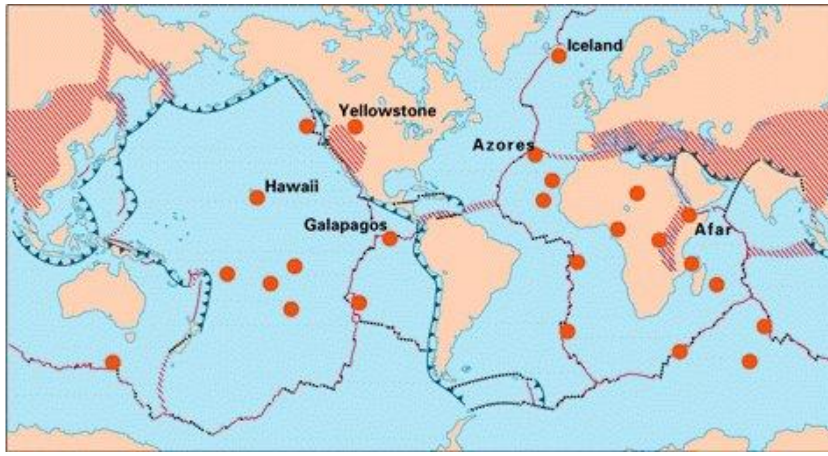
- The Reunion hotspot is a volcanic hotspot which currently lies under the Island of Reunion in the Indian Ocean.
- The Chagos-Laccadive Ridge (Lakshadweep is a part of this ridge) and the southern part of the Mascarene Plateau are volcanic traces of the Reunion hotspot.
- The hotspot is believed to have been active for over 66 million years. A huge eruption of this hotspot 66 million years ago is thought to have laid down the Deccan Traps, a vast bed of basalt lava that covers part of central India, and opened a rift which separated India from the Seychelles Plateau.

- As the Indian plate drifted north, the hotspot continued to punch through the plate, creating a string of volcanic islands and undersea plateaus.
- The Laccadive Islands, the Maldives, and the Chagos Archipelago are atolls resting on former volcanoes created 60-45 million years ago that subsequently submerged below sea level.
- About 45 million years ago the mid-ocean rift crossed over the hotspot, and the hotspot passed under the African Plate.
- The hotspot appears to have been relatively quiet from 45-10 million years ago, when activity resumed, creating the Mascarene Islands, which include Mauritius, Reunion, and Rodrigues.





Distribution of Hotspot Volcanism



In this post we will study about Earthquakes – Types of Seismic Waves or Earthquake waves.

Earthquakes

- An earthquake is the shaking or trembling of the earth's surface, caused by the sudden movement of a part of the earth's crust. They result from the sudden release of energy in the Earth's crust that creates seismic waves or earthquake waves.
- About 50,000 earthquakes large enough to be noticed without the aid of instruments occur annually over the entire Earth. Of these, approximately 100 are of sufficient size to produce substantial damage if their centers are near areas of habitation.

Terms associated with earthquakes

Focus

- The place of origin of an earthquake inside the earth.

Epicenter

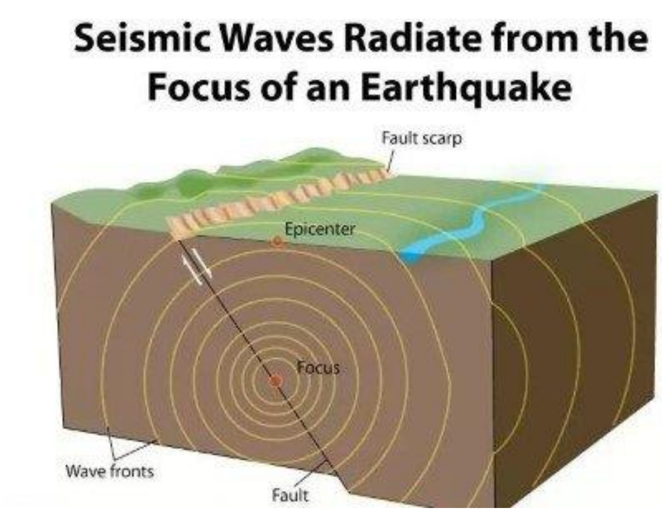
- Point on the earth's surface vertically above the focus.
- Maximum damage is caused at the epicenter.

Wave Velocity

- 5 to 8 km per second through the outer part of the crust but travel faster with depth.

Isoseismic Line

- A line connecting all points on the surface of the earth where the intensity is the same.



Causes of Earthquakes

- Most earthquakes are causally related to compressional or tensional stresses built up at the margins of the huge moving lithospheric plates.
- The immediate cause of most shallow earthquakes is the sudden release of stress along a fault, or fracture in the earth's crust.
- Sudden slipping of rock formations along faults and fractures in the earth's crust happen due to constant change in volume and density of rocks due to intense temperature and pressure in the earth's interior.
- 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 occur most often along geologic faults, narrow zones where rock masses move in relation to one another. The major fault lines of the world are located at the fringes of the huge tectonic plates that make up Earth's crust.
- Plate tectonics: Slipping of land along the fault line along, convergent, divergent and transform boundaries cause earthquakes. Example: San Andreas Fault is a transform fault where Pacific plate and North American plate move horizontally relative to each other causing earthquakes along the fault lines.

Human Induced Earthquakes

- Some earthquakes are human induced.
- Earthquakes in the reservoir region, mining sites etc. are human induced.

Some Earthquake inducing human activities

- Deep mining
- Underground nuclear tests
- Reservoir induced seismicity (RIS)
- Extraction of fossil fuels
- Groundwater extraction
- Artificial induction
- In fluid injection, the slip is thought to be induced by premature release of elastic strain, as in the case of tectonic earthquakes, after fault surfaces are lubricated by the liquid.

Volcanic Earthquakes

- A separate type of earthquake is associated with volcanic activity and is called a volcanic earthquake.
- Yet it is likely that even in such cases the disturbance is the result of a sudden slip of rock masses adjacent to the volcano and the consequent release of elastic strain energy.
- The stored energy, however, may in part be of hydrodynamic origin due to heat provided by magma moving in reservoirs

beneath the volcano or to the release of gas under pressure.

- There is a clear correspondence between the geographic distribution of volcanoes and major earthquakes, particularly in the Circum-Pacific Belt and along oceanic ridges.
- Volcanic vents, however, are generally several hundred kilometres from the epicenters of most major shallow earthquakes, and many earthquake sources occur nowhere near active volcanoes.
- Even in cases where an earthquake's focus occurs directly below structures marked by volcanic vents, there is probably no immediate causal connection between the two activities; most likely both are the result of the same tectonic processes.

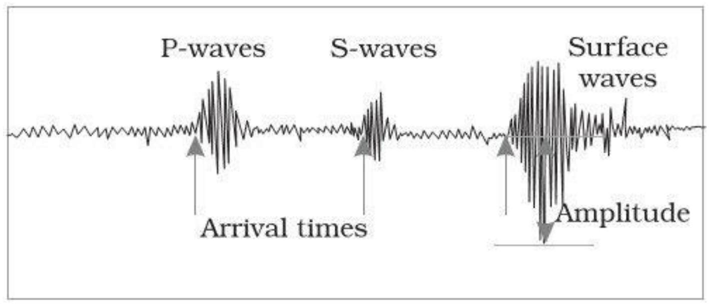
Seismic Waves or Earthquake Waves

- The slipping of land generates seismic waves and these waves travel in all directions.
- Earthquake is any sudden shaking of the ground caused by the passage of seismic waves through Earth's rocks. (Earthquake is caused by vibrations in rocks. And the vibrations in rocks are produced by seismic waves)
- Seismic waves are produced when some form of energy stored in Earth's crust is suddenly released, usually when masses of rock straining against one another suddenly fracture and "slip."

Types of Seismic Waves

- Earthquake waves are basically of two types — **body waves** and **surface waves.**
- Body waves are generated due to the release of energy at the focus and move in all directions travelling through the body of the earth. Hence, the name body waves.
- The body waves interact with the surface rocks and generate new set of waves called surface waves. These waves move along the surface.
- The velocity of waves changes as they travel through materials with different elasticity (stiffness) (Generally density with few exceptions). The more elastic the material is, the higher is the velocity. Their direction also changes as they reflect or refract when coming across materials with different densities.
- There are two types of body waves. They are called P and S-waves.

1. **Primary waves or P waves (longitudinal)(fastest)**
2. **Secondary waves or S waves (transverse)(least destructive)**
3. **Surface waves or L waves (transverse)(slowest)(most destructive)**



Primary Waves (P waves)

- Also called as the **longitudinal or compressional waves.**
- Analogous to **sound waves.**
- Particles of the medium vibrate along the direction of propagation of the wave.
- P-waves move faster and are the **first to arrive at the surface**.
- These waves are of high frequency.
- They can travel in **all mediums**.
- Velocity of P waves in **Solids > Liquids > Gases**.
- Their velocity depends on shear strength or elasticity of the material.

[We usually say that the speed of sound waves depends on density. But there are few exceptions. For example: Mercury (liquid metal) has density greater than Iron but speed of sound in mercury is lesser compared to that in iron. This is because the shear strength of mercury is very low (this is why mercury is liquid) compared to that of iron.]

Secondary Waves (S waves)

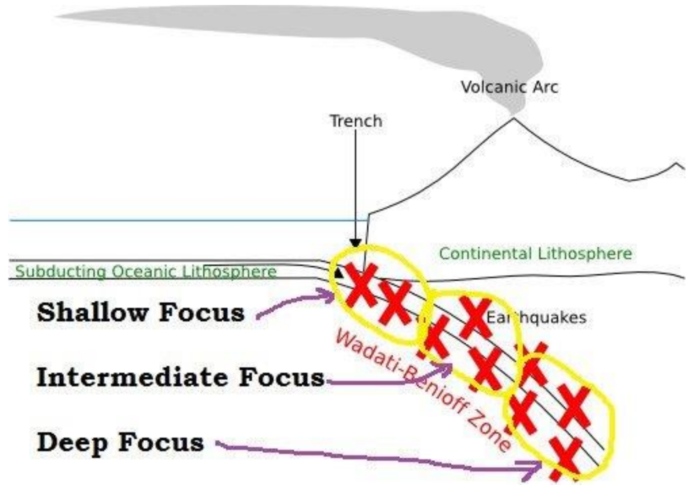
- Also called as **transverse or distortional waves**.
- Analogous to **water ripples or light waves**.
- S-waves arrive at the surface with some time lag.
- A secondary wave **cannot pass through liquids or gases**.
- These waves are of high frequency waves.
- Travel at varying velocities (proportional to shear strength) through the solid part of the Earth's crust, mantle.

Surface Waves (L waves)

- Also called as **long period waves**.
- They are **low frequency, long wavelength, and transverse vibration**.
- Generally affect the surface of the Earth only and die out at smaller depth.
- Develop in the immediate neighborhood of the epicenter.
- They cause displacement of rocks, and hence, the collapse of structures occurs.
- These waves are the **most destructive.**
- Recoded last on the seismograph.

Earthquakes based on the depth of Focus

- Wadati Benioff zone is a zone of subduction along which earthquakes are common.
- A **Wadati–Benioff zone** is a zone of seismicity corresponding with the down-going slab in a subduction zone (Convergent Boundary).
- Differential motion along the zone produces numerous earthquakes.
- Shallow focus earthquakes (most common at submarine ridges. Hardly felt)
- Intermediate focus earthquakes (somewhat severe)
- Deep focus earthquakes (Occurs at trenches – convergent boundary. Very powerful. Japan lies along trench line. Hence it faces devastating earthquakes)



- Shallow focus earthquakes are called **crustal earthquakes** as they exist in the earth's crustal layer.
- Deep focus earthquakes are known as **intra plate earthquakes**, as they are triggered off by collision between plates.
- Shallow-focus earthquakes occur at depths less than 70 km, while deep-focus earthquakes occur at greater focal depths of **300 – 700 km.**
- 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 focus earthquakes are of smaller magnitudes, of a range 1 to 5, while deep focus earthquakes are of higher magnitudes, 6 to 8 or more.

Distribution of Earthquakes

- Earth's major earthquakes occur mainly in belts coinciding with the margins of tectonic plates.
- 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.
- The seismic activity is by no means uniform throughout the belt, and there are a number of branches at various points. Because at many places the Circum-Pacific Belt is associated with volcanic activity, it has been popularly dubbed the

"Pacific Ring of Fire." The Pacific Ring of Fire accounts for about 68 per cent of all earthquakes.

- A second belt, known as the Alpine Belt (Himalayas and Alps). The energy released in earthquakes from this belt is about 15 percent of the world total. 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. This zone has folded mountains, large depressions and active volcanoes.
- 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**.

Effects of Earthquakes

- Earthquakes cause landslides, damming of rivers, depressions which form lakes.
- They can cause submergence and emergence of landforms along coastal regions. Example: Coastline of Kutch.
- Lead to change in surface drainage and underground circulation of water.
- More devastating features of earthquakes are fires and seismic waves (tsunamis).
- Formation of cracks or fissures especially in the region of the epicenter is common.

Richter scale of earthquake magnitude			
magnitude level	**category**	**effects**	**earthquakes per year**
less than 1.0 to 2.9	micro	generally not felt by people, though recorded on local instruments	more than 100,000
3.0-3.9	minor	felt by many people; no damage	12,000-100,000
4.0-4.9	light	felt by all; minor breakage of objects	2,000-12,000
5.0-5.9	moderate	some damage to weak structures	200-2,000
6.0-6.9	strong	moderate damage in populated areas	20-200
7.0-7.9	major	serious damage over large areas; loss of life	3-20
8.0 and higher	great	severe destruction and loss of life over large areas	fewer than 3

Tsunamis are the most disastrous among natural calamities. Though their occurrence is rare, the havoc they cause is tremendous. The latest is the Japan Earthquake & Tsunami of 2011 which caused death of more than 15,000 individuals. The tsunami caused nuclear accidents, primarily the meltdowns at three reactors in the Fukushima Daiichi Nuclear Power Plant complex.

Tsunami

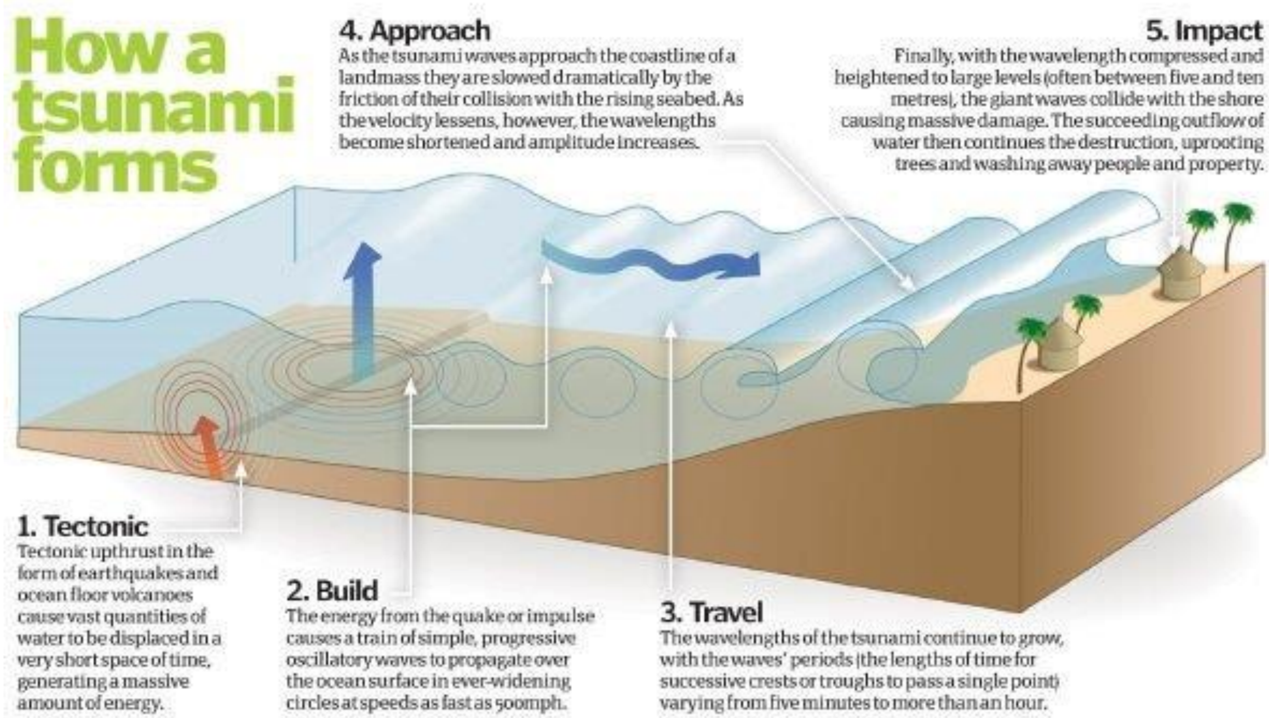
- Tsunami is a Japanese word for "**Harbour wave**". They are also known as seismic sea waves.
- They are very long-wavelength water waves in oceans or seas. They are commonly referred to as **tidal waves** because of **long wavelengths**, although the attractions of the Moon and Sun play no role in their formation.
- They sometimes come ashore to great heights – tens of metres above mean tide level – and may be extremely destructive.

What causes Tsunami?

- A tsunami can be caused by any disturbance that displaces a large water mass from its equilibrium position.
- The usual immediate cause of a tsunami is sudden displacement in a seabed due to submarine earthquakes sufficient to cause the sudden raising or lowering of a large body of water. The tsunami on December 26, 2004 was caused after an earthquake displaced the seabed off the coast of Sumatra, Indonesia.
- Large volcanic eruptions along shorelines, such as Krakatoa (1883 CE), have also produced notable tsunamis.
- A marine volcanic eruption can generate an impulsive force that displaces the water column and gives birth to a tsunami.
- During a submarine landslide, the equilibrium sea-level is altered by sediment moving along the floor of the sea. Gravitational forces then propagate a tsunami.
- Landslides along the coast, high intensity explosions can also cause tsunami.
- Most destructive tsunamis can be caused due to the fall of extra-terrestrial objects on to the earth.

Mechanism in Earthquake induced Tsunami's

- An undersea earthquake causes buckling of the sea floor, something that occurs at subduction zones, places where drifting plates that constitute the outer shell of the earth converge and the heavier oceanic plate subducts below the lighter continents.
- As a plate plunges into the interior of the earth it gets stuck against the edge of a continental plate for a while, when stresses build up, then the locked zone gives way. Parts of the ocean floor then snap upward and other areas sink downward.
- In the instant after the quake, the sea surface shape resembles the contours of the seafloor. But then gravity acts to return the sea surface to its original shape. The ripples then race outward and a tsunami is caused.

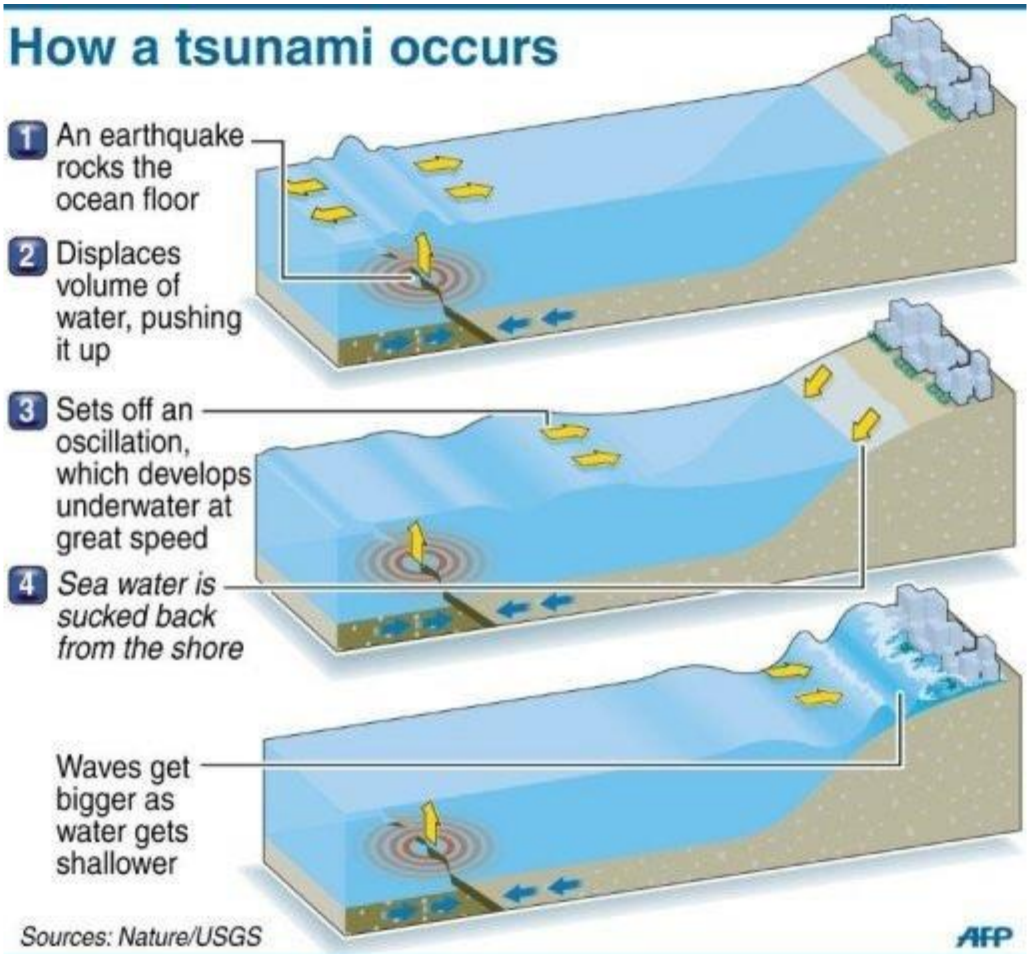


Propagation of tsunami waves

- The long gravity tsunami waves are caused by two interacting processes.

1. There is the slope of the sea surface which creates a horizontal pressure force.
2. Then there is the piling up or lowering of sea surface as water moves in varying speeds in the direction that the wave form is moving. These processes together create propagating waves.

- As a tsunami leaves deep waters and propagates into the shallow waters, it transforms. This is because as the depth of the water decreases, the speed of the tsunami reduces. But the change of total energy of the tsunami remains constant.
- With decrease in speed, height of the tsunami wave grows. A tsunami which was imperceptible in deep water may grow to many metres high and this is called the **'shoaling' effect**.
- Sometimes, the sea seems to at first draw a breath but then this withdrawal is followed by arrival of the crest of a tsunami wave. Tsunamis have been known to occur suddenly without warning.
- In some cases there are several great waves separated by intervals of several minutes or more. The first of these waves is often preceded by an extraordinary recession of water from the shore, which may commence several minutes or even half an hour beforehand.



Properties of Tsunami Waves

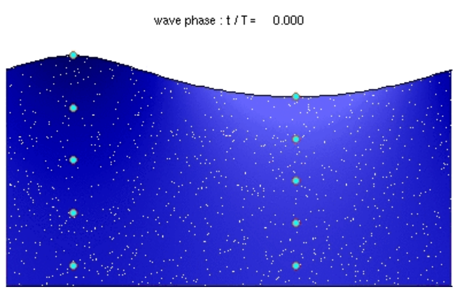
- Tsunamis are a series of waves of very, very long wavelengths and period created in oceans by an impulsive disturbance.
- Tsunamis are different from the wind-generated waves which usually have a period of five to twenty seconds.
- Tsunamis behave as **shallow-water waves** because of their long wavelengths. They have a period in the range of ten minutes to two hours and a wavelength exceeding 500 km.
- The rate of energy loss of a wave is inversely related to its wavelength. So tsunamis lose little energy as they propagate because of their very large wavelength.
- So they will travel at high speeds in deep waters and travel great distances as well losing little energy. A tsunami that occurs 1000 metres deep in water has a speed of 356 km per hour.
- At 6000 m, it travels at 873 km per hour.
- It travels at different speeds in water: it travels slow in water that is shallow and fast in deep water.

Waves

- The horizontal and vertical motions are common in ocean water bodies. The **horizontal motion** refers to the **ocean currents and waves**. The **vertical motion** refers to **tides**.
- **Water moves ahead from one place to another through ocean currents while the water in the waves does not move, but the wave trains move ahead.**
- Waves are actually the **energy**, not the water as such, which moves across the ocean surface. Water particles only travel in a small circle as a wave passes.
- **Wind** provides energy to the waves. Wind causes waves to travel in the ocean and the energy is released on shorelines.
- The motion of the surface water seldom affects the stagnant deep bottom water of the oceans.

- As a wave approaches the beach, it slows down. This is due to the friction occurring between the dynamic water and the sea floor.

And, when the depth of water is less than half the wavelength of the wave, the wave breaks (dies).



Gif Image

- The largest waves are found in the open oceans. Waves continue to grow larger as they move and absorb energy from the wind.
- When a breeze of two knots or less blows over calm water, small ripples form and grow as the wind speed increases until white caps appear in the breaking waves.
- Waves may travel thousands of km before rolling ashore, breaking and dissolving as surf. A wave's size and shape reveal its origin.

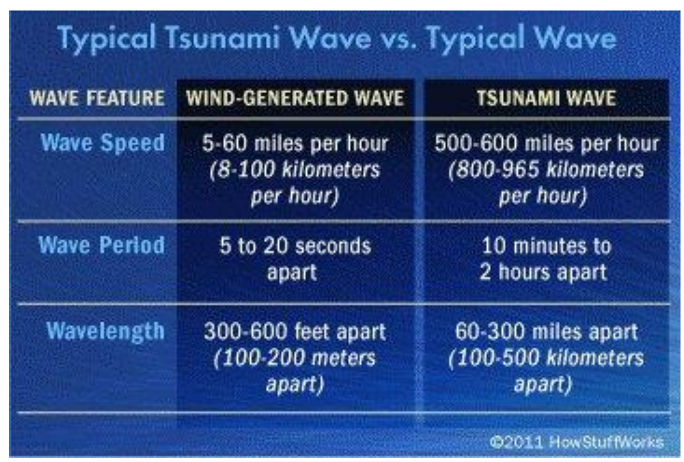
Steep waves are fairly young ones and are probably formed by local wind. Slow and steady waves originate from faraway places, possibly from another hemisphere.

- Waves travel because wind pushes the water body in its course while gravity pulls the crests of the waves downward.
- The falling water pushes the former troughs upward, and the wave moves to a new position.
- The actual motion of the water beneath the waves is **circular**. It indicates that things are carried up and forward as the wave approaches, and down and back as it passes.

Characteristics of Waves

- Wave crest and trough: The highest and lowest points of a wave are called the crest and trough respectively.
- Wave height: It is the vertical distance from the bottom of a trough to the top of a crest of a wave.
- Wave amplitude: It is one-half of the wave height.
- Wave period: It is merely the time interval between two successive wave crests or troughs as they pass a fixed point.
- Wavelength: It is the horizontal distance between two successive crests.
- Wave speed: It is the rate at which the wave moves through the water, and is measured in knots.
- Wave frequency: It is the number of waves passing a given point during a one second time interval.

Normal waves vs Tsunami waves


Typical Tsunami Wave vs. Typical Wave

WAVE FEATURE	WIND-GENERATED WAVE	TSUNAMI WAVE
Wave Speed	5-60 miles per hour *(8-100 kilometers per hour)*	500-600 miles per hour *(800-965 kilometers per hour)*
Wave Period	5 to 20 seconds apart	10 minutes to 2 hours apart
Wavelength	300-600 feet apart *(100-200 meters apart)*	60-300 miles apart *(100-500 kilometers apart)*

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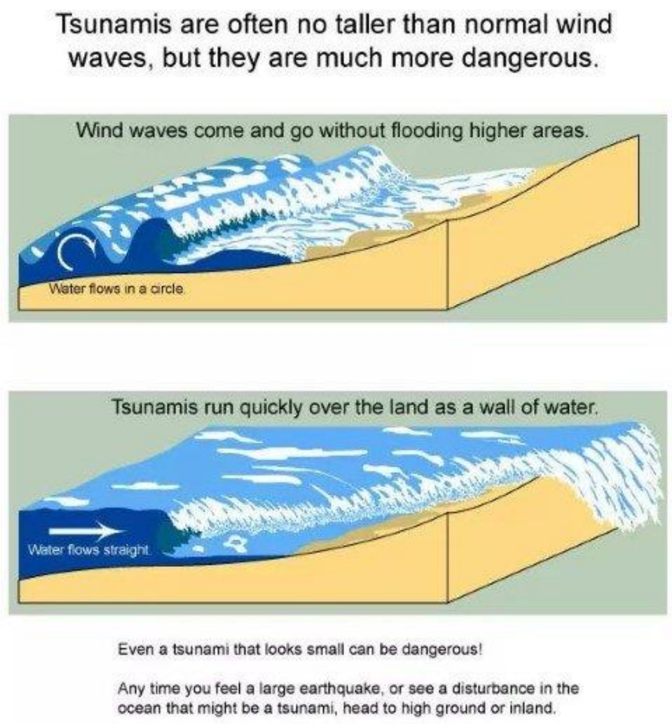
Tsunami waves are not noticed by ships far out at sea

- As tsunami waves are long wavelength waves, they cannot be perceived in deep oceans. Their amplitude is negligible when compared with their wavelength and hence the waves go unnoticed in deep oceans.
- When tsunamis approach shallow water, however, the wave amplitude increases (conservation of energy). The waves may occasionally reach a height of 20 to 30 metres above mean sea level in U- and V-shaped harbours and inlets (funneling effect).



2004 Indian Ocean Tsunami

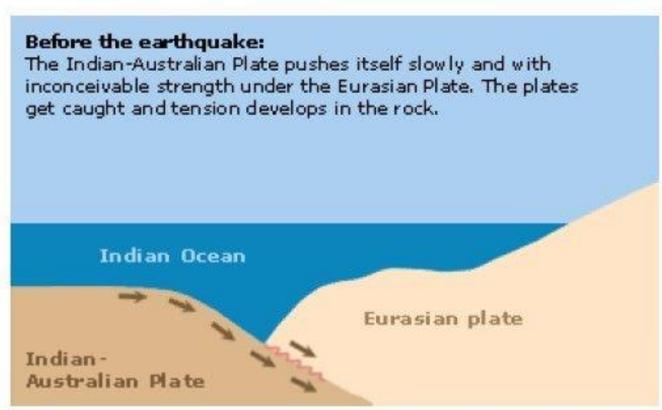
- Tsunami or the Harbour wave struck havoc in the Indian Ocean on the 26th of December 2004.
- The wave was the result of earthquake that had its epicenter near western boundary of Sumatra.
- The magnitude of the earthquake was 9.0 on the Richter scale.

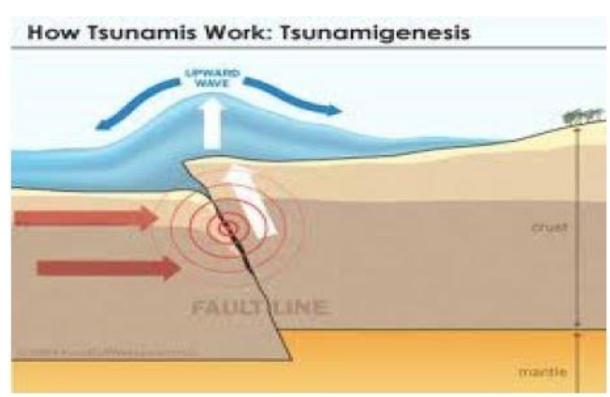
Plate tectonics

- **Indian plate** went under the **Burma plate**, there was a sudden movement of the sea floor, causing the earthquake.
- The ocean floor was displaced by about 10 – 20m and tilted in a downwardly direction.
- A huge mass of ocean water flowed to fill in the gap that was being created by the displacement.
- This marked the withdrawal of the water mass from the coastlines of the landmasses in the south and Southeast Asia.
- After thrusting of the Indian plate below the Burma plate, the water mass rushed back towards the coastline as tsunami.

Tsunami waves

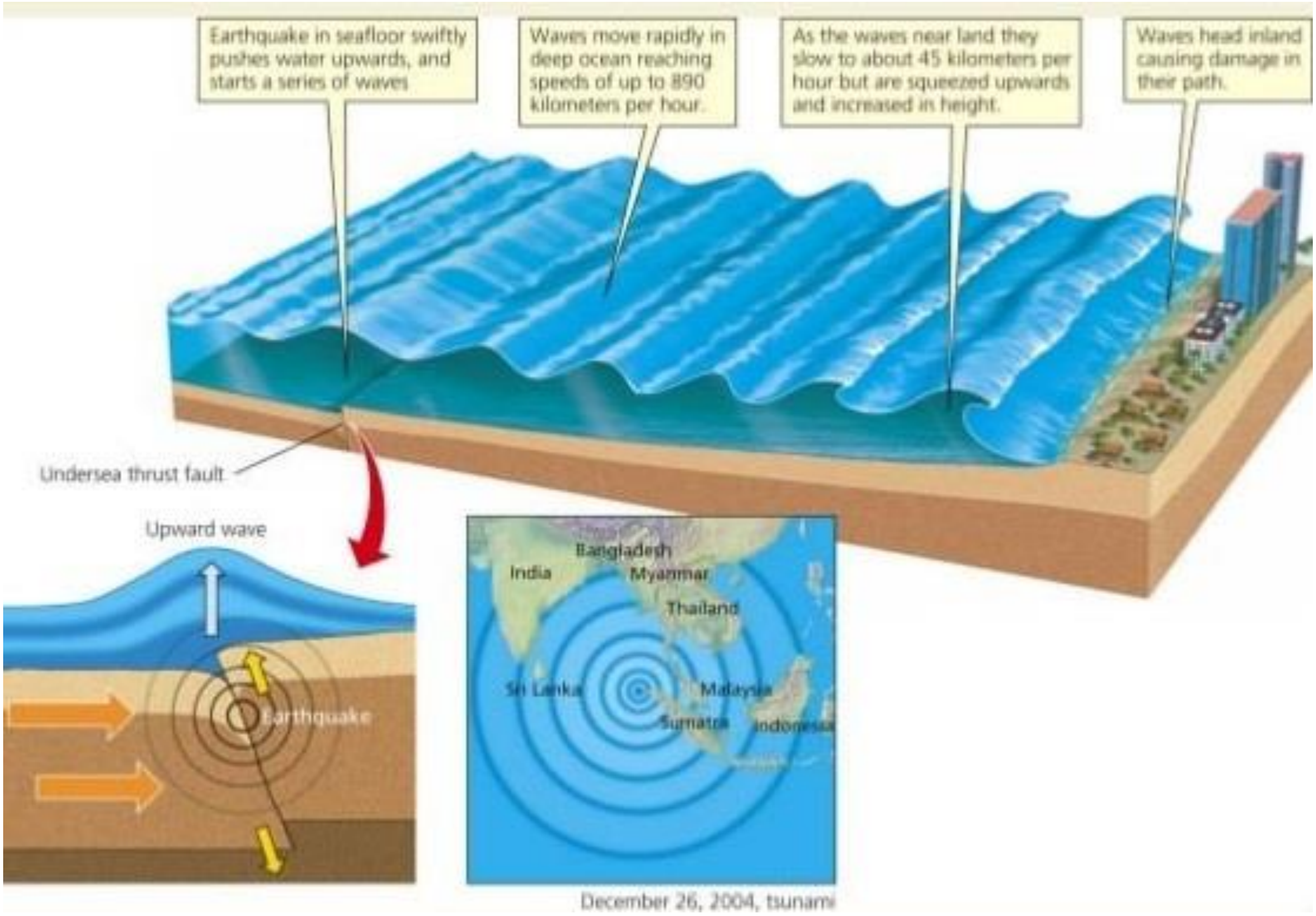
- Tsunami traveled at a speed of about 800 km. per hour, comparable to speed of commercial aircraft and completely washed away some of the islands in the Indian ocean.
- The Indira point in the Andaman and Nicobar islands that marked the southernmost point of India got completely submerged.
- As the wave moved from earthquake epicenter from Sumatra towards the Andaman Islands and Sri Lanka the **wave length decreased with decreasing depth of water**. The travel speed also declined from 700-900 km. per hour to less than 70 km. per hour.
- Tsunami waves traveled up to a depth of 3 km from the coast killing more than 10,000 people and affected more than lakh of houses.
- In India, the worst affected were the coastal areas of Andhra Pradesh, Tamil Nadu, Kerala, Pondicherry and the Andaman and Nicobar Islands.





Occurrence

- Subduction zones off Chile, Nicaragua, Mexico and Indonesia have created killer tsunamis.
- The Pacific among the oceans has witnessed most number of tsunamis (over 790 since 1990).



December 26, 2004, tsunami

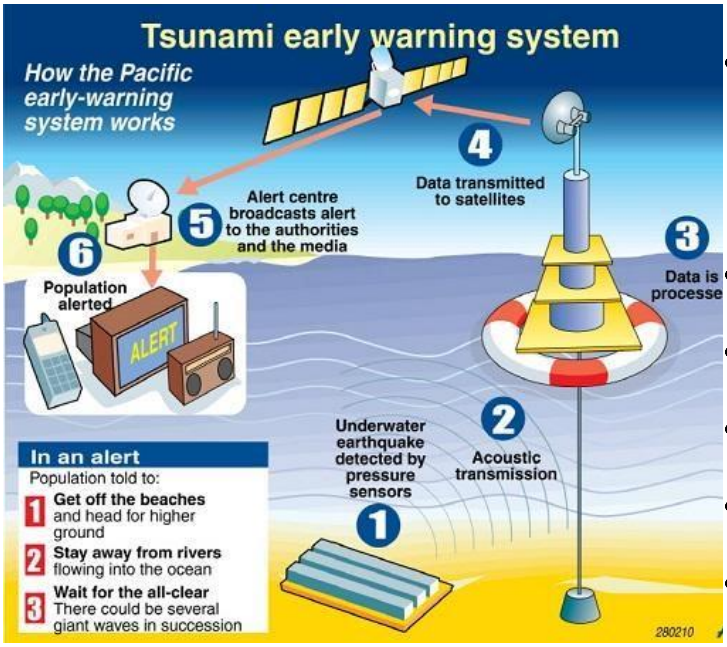
Shifts in Geography

- Tsunamis and earthquakes can cause changes in geography.
- The December 26 earthquake and tsunami shifted the North Pole by 2.5 cm in the direction of 145 degrees East longitude and reduced the length of the day by 2.68 microseconds.
- This in turn affected the velocity of earth's rotation and the Coriolis force which plays a strong role in weather patterns.
- The Andaman and Nicobar Islands may have (moved by about 1.25 m owing to the impact of the colossal earthquake and the tsunami.

Warning Systems

- While the earthquake cannot be predicted in advance, it is possible to give a three-hour notice of a potential tsunami.
- Such early warning systems are in place across the Pacific Ocean. Post 2004, they were installed in Indian Ocean as well.
- In 1965, early warning system was started by the National Oceanic and Atmospheric Administration (NOAA). The member states of the NOAA include the major Pacific Rim countries.
- NOAA has developed the **'Deep Ocean Assessment and Reporting of Tsunamis' (DART) gauge.**
- Each gauge has a very sensitive pressure recorder on the sea floor. Data is generated whenever changes in water pressure occur.

- The data is transmitted to a surface **buoy** which then relays it over satellite.
- Computer systems at the **Pacific Tsunami Warning Centre (PTWC) in Hawaii** monitors data.
- Based on the data, warnings are issued.



India's preparedness

- The Deep Ocean Assessment and Reporting System (DOARS) was set up in the Indian Ocean post 2014.
- The Indian government plans to set up a network with Indonesia, Myanmar and Thailand etc..
- A **National Tsunami Early Warning Centre**, which has the capability to detect earthquakes of more than 6 magnitude in the Indian Ocean, was inaugurated in 2007 in India.
- Set up by the **Ministry of Earth Sciences** in the **Indian National Centre for Ocean Information Services (INCOIS), Hyderabad**, the tsunami warning system would take 10-30 minutes to analyze the seismic data following an earthquake.

ROCKS

- **Feldspar** and **quartz** are the most common minerals found in rocks.
- **Petrology** is science of rocks.

Different kinds of rocks

- **Igneous Rocks** — solidified from magma and lava.
- **Sedimentary Rocks** — the result of deposition of fragments of rocks.
- **Metamorphic Rocks** — formed out of existing rocks undergoing recrystallization.

Igneous Rocks

- Formed out of magma and lava and are known as **primary rocks**.
- If molten material is cooled slowly at great depths, mineral grains may be very large.
- Sudden cooling (at the surface) results in small and smooth grains.
- Granite, gabbro, pegmatite, basalt, etc.are some of the examples of igneous rocks.
- There are two types of igneous rocks: **intrusive rocks (Granite)** and **extrusive rocks (Basalt-Deccan Traps).**
- Having their origin under conditions of high temperatures, the igneous rocks are **Unfossiliferous.**
- Acid igneous rocks, such as granite, are less dense and are lighter in colour than basic rocks.

Based on place and time taken in cooling of the molten matter, igneous rocks can be divided into Plutonic and Volcanic rocks.

Plutonic Rocks or intrusive rocks

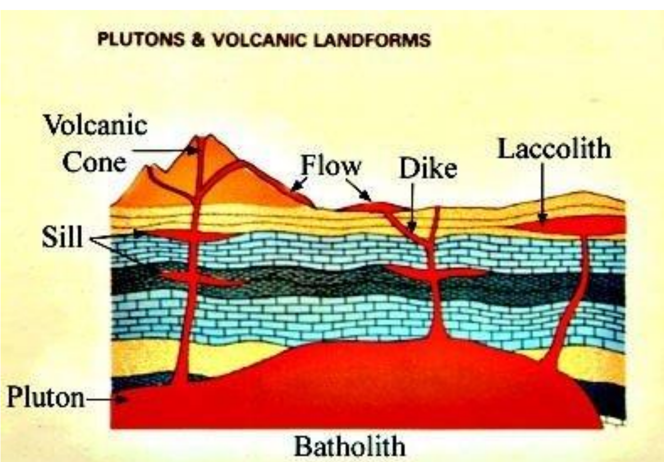
- Sometimes, the molten matter is not able to reach the surface and instead cools down very slowly at great depths.
- Slow cooling allows big-sized crystals (large grains) to be formed.
- **Granite** is a typical example. These rocks appear on the surface only after being uplifted and denuded.

Lava or Volcanic Rocks or Extrusive rocks

- These are formed by rapid cooling of the lava thrown out during volcanic eruptions.
- Rapid cooling prevents crystallization, as a result such rocks are fine-grained.
- Basalt is a typical example. The Deccan traps in the peninsular region is of basaltic origin.
- Basic rocks contain a greater proportion of **basic oxides**, e.g. of iron, aluminium or magnesium, and are thus **denser and darker in colour**.

Plutonic rocks	Volcanic rocks
Intrusive rocks	Extrusive rocks
Granite	Basalt
Slow cooling allows big-sized crystals (large grains)	Rapid cooling prevents crystallization, as a result such rocks are fine-grained
Less dense and are lighter in colour than basic rocks	Denser and Darker in colour

Hypabyssal or Dyke Rocks or Intermediate rocks



- These rocks occupy an intermediate position between the deep-seated plutonic bodies and the surface lava flows.
- Dyke rocks are semi-crystalline in structure.

Based on the presence of acid forming radical, silicon, igneous rocks are divided into Acid Rocks and Basic Rocks.

Acid Rocks

- These are characterized by high content of silica—up to 80 per cent, while the rest is divided among aluminium, alkalis, magnesium, iron oxide, lime etc..
- These rocks constitute the sial portion of the crust.
- Due to the excess of silicon, acidic magma cools fast and it does not flow and spread far away.
- High mountains are formed of this type of rock.
- These rocks have a lesser content of heavier minerals like iron and magnesium and normally contain quartz and feldspar.
- Add rocks are hard, compact, massive and resistant to weathering.

Basic Rocks

- These rocks are poor in silica (about 40 per cent); magnesia content is up to 40 per cent and the remaining 40 per cent is spread over iron oxide, lime, aluminium, alkalis, potassium etc.
- Due to low silica content, the parent material of such rocks cools slowly and thus, flows and spreads far away. This flow and cooling gives rise to plateaus.
- Presence of heavy elements imparts to these rocks a dark colour.
- Basalt is a typical example, others being gabbro and dolerite.
- Not being very hard, these rocks are weathered relatively easily.

Acidic rocks	Basic rocks
High content of silica—upto 80 per cent	Poor in silica; magnesia content (40

	per cent)
Due to the excess of silicon, acidic magma cools fast	Due to low silica content, the parent material of such rocks cools slowly
High Volcanic mountains are formed of this type of rock. Mt Fuji, Japan	Forms plateaus. Deccan Traps
Lesser content of heavier minerals like iron and magnesium and normally contain quartz and feldspar. Hence they are lighter in colour	Presence of heavy elements imparts to these rocks a dark colour.
Granite, quartz, feldspar etc.	Basalt, gabbro, dolerite etc..
Add rocks are hard, compact, massive and resistant to weathering.	Not being very hard, these rocks are weathered relatively easily.

Economic Significance of Igneous Rocks

- Since magma is the chief source of metal ores, many of them are associated with igneous rocks.
- The minerals of great economic value found in igneous rocks are magnetic iron, nickel, copper, lead, zinc, chromite, manganese, gold, diamond and platinum.
- Amygdales are almond-shaped bubbles formed in basalt due to escape of gases and are filled with minerals.
- The old rocks of the great Indian peninsula are rich in these crystallised minerals or metals.
- Many igneous rocks like granite are used as building material as they come in beautiful shades.

Sedimentary Rocks

- Sedimentary or detrital rocks.
- Formed as a result of denudation (weathering and erosion).
- These deposits through compaction turn into rocks. This process is called **lithification.**
- Cover 75 per cent of the earth's crust but volumetrically occupy only 5 per cent.
- They are layered or stratified of varying thickness. Example: sandstone, shale etc.
- Till or Tillite == Ice deposited sedimentary rocks.
- Loess == Wind deposited sediments.

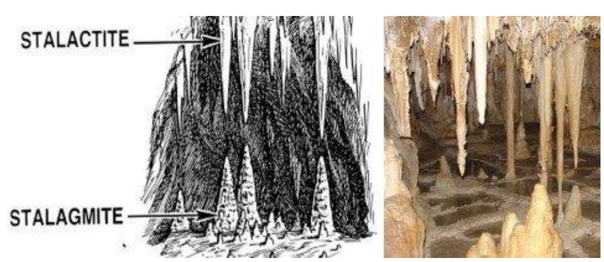
Depending upon the mode of formation, they are classified into

- mechanically formed — sandstone, conglomerate, limestone, shale, loess etc.
- organically formed — geyserite, chalk, limestone, coal etc.
- chemically formed — chert, limestone, halite, potash etc..

Mechanically Formed Sedimentary Rocks

- Formed by mechanical agents like running water, wind, ocean currents, ice, etc.
- Arenaceous rocks == More sand and big sized particles, and are hard. E.g. sandstone.
- Argillaceous rocks == More clay and are fine-grained, softer, impermeable and non-porous. They are easily weathered and eroded. E.g. shale.

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

- The remains of plants and animals are buried under sediments and due to heat and pressure from overlying layers, their composition undergoes a change.
- Coal and limestone are well-known examples.
- Plant remains give rise to coals of different grades depending upon the proportion of carbon and the degree of overlying pressure.
- The peat and lignite (brown coal) is the first stage of coal having below 45 per cent of carbon; the bituminous variety is the next stage with 60 per cent carbon.
- Limestone is composed of shells and skeletons of dead marine animals that once lived in shallow, warm and clear waters of a sea or lake.
- Depending on the predominance of calcium content or the carbon content, sedimentary rocks may be calcareous (limestone, chalk, dolomite) or carbonaceous (coal).

Chief Characteristics of Sedimentary Rocks

- These rocks consist of a number of layers or strata
- These rocks are characterized by marks left behind by water currents and waves etc..
- These rocks have fossils of plants and animals.
- These rocks are generally porous and allow water to percolate through them.
- Spread of Sedimentary Rocks in India
- Alluvial deposits in the Indo-Gangetic plain and coastal plains is of sedimentary accumulation.
- These deposits contain loam and clay.
- Different varieties of sandstone are spread over Madhya Pradesh, eastern Rajasthan, parts of Himalayas, Andhra Pradesh, Bihar and Orissa.
- The great Vindhyan highland in central India consists of sandstones, shales, limestones.
- Coal deposits occur in river basins of the Damodar, Mahanadi, Godavari in the Gondwana sedimentary deposits.

Economic Significance of Sedimentary Rocks

- Sedimentary rocks are not as rich in minerals of economic value as the igneous rocks.
- But important minerals such as hematite iron ore, phosphates, building stones, coals, petroleum and material used in cement industry are found.
- The decay of tiny marine organisms yields petroleum. Petroleum occurs in suitable structures only.
- Important minerals like bauxite, manganese, tin are derived from other rocks but are found in gravels and sands carried by water. Sedimentary rocks also yield some of the richest soils.

Metamorphic Rocks

- The word metamorphic means **'change of form'.**
- Form under the action of pressure, volume and temperature (PVT) changes.
- Metamorphism occurs 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.
- Metamorphism is a process by which already consolidated rocks undergo recrystallization and reorganization of materials within original rocks.
- 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.
- Sometimes minerals or materials of different groups are arranged into alternating thin to thick layers. Such a structure in is called banding.

- Gneissoid, slate, schist, marble, quartzite etc. are some examples of metamorphic rocks.

Causes of Metamorphism

Orogenic (Mountain Building) Movements

- Such movements often take place with interplay of folding, warping, crumpling and high temperatures. These processes give existing rocks a new appearance.
- Lava Inflow The molten magmatic material inside the earth's crust brings the surrounding rocks under the influence of intense temperature pressure and causes changes in them.

Geodynamic Forces

- The omnipresent geodynamic forces such as plate tectonics also play an important role in metamorphism.

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

Thermal Metamorphism

- The change of form or re-crystallisation of minerals of sedimentary and igneous rocks under the influence of high temperatures is known as thermal metamorphism.
- There may be various sources of the'high temperatures—hot magma, hot gases, vapours and liquids, geothermal heat etc.
- A magmatic intrusion causing thermal metamorphism is responsible for the peak of Mt. Everest consisting of metamorphosed limestone.
- As a result of thermal metamorphism, sandstone changes into quartzite and limestone into marble.

Dynamic Metamorphism

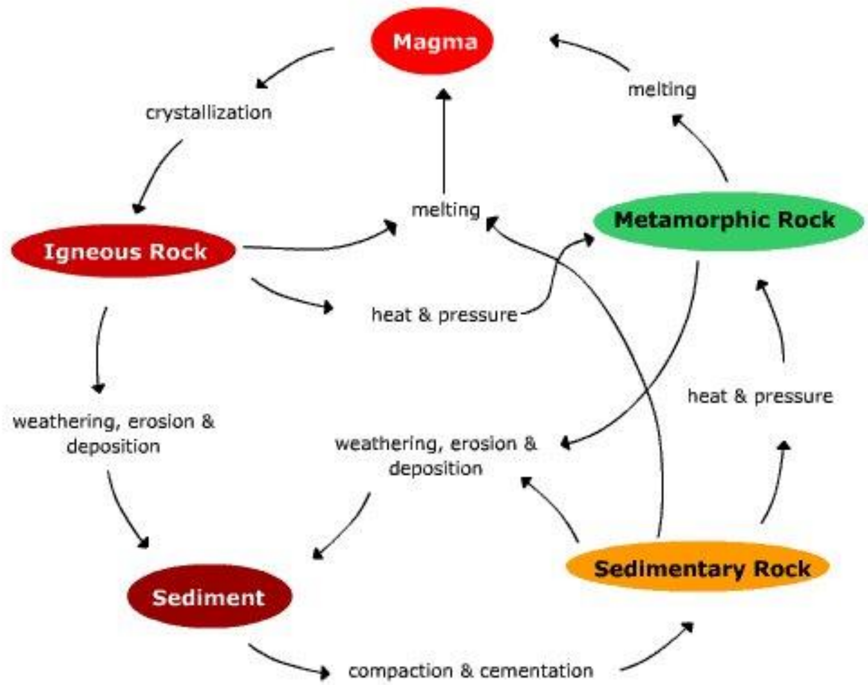
- This refers to the formation of metamorphic rocks under the stress of pressure.
- Sometimes high pressure is accompanied by high temperatures and the action of chemically charged water.
- The combination of directed pressure and heat is very powerful in producing metamorphism because it leads to more or less complete recrystallisation of rocks and the production of new structures. This is known as dynamothermal metamorphism.
- Under high pressure, granite is converted into gneiss; clay and shale are transformed into schist.

Some Examples of Metamorphism

Granite $\xrightarrow{\text{Pressure}}$ Gneiss
Clay, Shale $\xrightarrow{\text{Pressure}}$ Schist
Sandstone $\xrightarrow{\text{Heat}}$ Quartzite
Clay, Shale $\xrightarrow{\text{Heat}}$ Slate $\xrightarrow{\text{Heat}}$ Phyllite
Coal $\xrightarrow{\text{Heat}}$ Anthracite, Graphite
Limestone $\xrightarrow{\text{Heat}}$ Marble

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.
- Marble occurs near Alwar, Ajmer, Jaipur, Jodhpur in Rajasthan and parts of Narmada Valley in Madhya Pradesh.
- Slate, which is used as a roofing material and for writing in schools, is found over Rewari (Haryana), Kangra (Himachal Pradesh) and parts of Bihar.
- Graphite is found in Orissa and Andhra Pradesh.

Rock cycle

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

Some Rock-Forming Minerals

- Feldspar: Half the crust is composed of feldspar. It has a light colour and its main constituents are silicon, oxygen, sodium, potassium, calcium, aluminium.
- Quartz: It has two elements, silicon and oxygen. It has a hexagonal crystalline structure. It is uncleavaged, white or colorless. It cracks like glass and is present in sand and granite. It is used in manufacture of radio and radar.
- Bauxite: A hydrous oxide of aluminium, it is the Ore of aluminium. It is non-crystalline and occurs in small pellets.

- Cinnabar: It is mercury sulphide and mercury is derived from it. It has a brownish colour.
- Dolomite: A double carbonate of calcium and magnesium. It is used in cement and iron and steel industries. It is white in colour.
- Gypsum: It is hydrous calcium sulphate and is used in cement, fertilizer and chemical industries.
- Haematite: It is a red ore of iron.
- Magnetite: It is the black ore (or iron oxide) of iron.

Multiple choice questions.

1. Which one of the following are the two main constituents of granite? (a) Iron and nickel (c) Silica and aluminium (b) Iron and silver (d) Iron Oxide and potassium
2. Which one of the following is the salient feature of metamorphic rocks? (a) Changeable (c) Crystalline (b) Quite (d) Foliation
3. Which one of the following is not a single element mineral? (a) Gold (c) Mica (b) Silver (d) Graphite
4. Which one of the following is the hardest mineral? (a) Topaz (c) Quartz (b) Diamond (d) Feldspar
5. Which one of the following is not a sedimentary rock? (a) Tillite (c) Breccia (b) Borax (d) Marble

Fluvial Erosional Landforms are landforms created by the erosional activity of rivers.

Landforms and Cycle of Erosion

- Fluvial landforms and Cycle of Erosion – Deposition Landforms [This Post] and Erosional Landforms [Next Post].
- Glacial landforms and Cycle of Erosion
- Marine landforms and Cycle of Erosion
- Arid landforms and Cycle of Erosion
- Karst landforms and Cycle of Erosion

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.

Fluvial Erosional Landforms

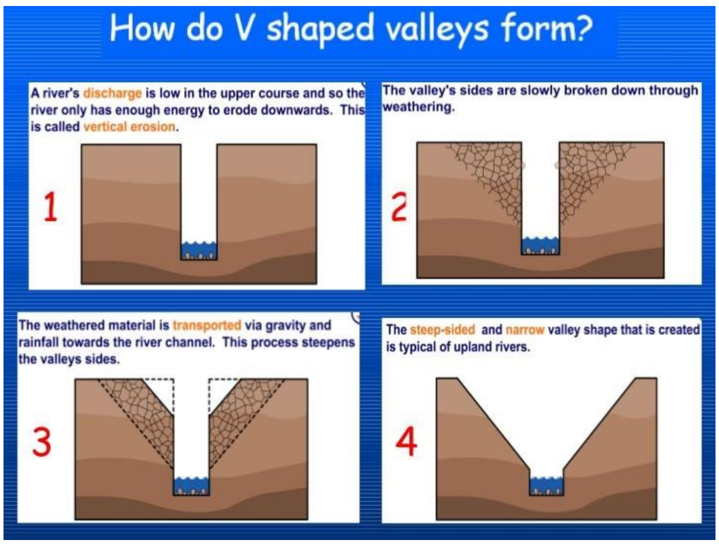
Various Aspects of Fluvial Erosive Action

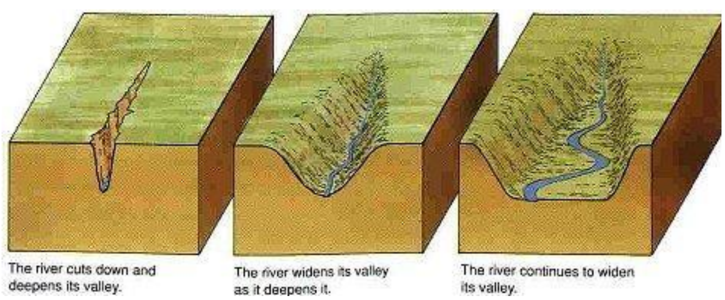
- Corrasion or abrasion == solid river load striking against rocks and wearing them down.
- Hydration == force of running water wearing down rocks.
- Attrition == river load particles striking, colliding against each other and breaking down in the process.
- Downcutting == Erosion in vertical direction (downcutting leads to valley deepening) or
- Lateral erosion == Erosion in horizontal direction, especially the walls of the stream.
- Corrosion == Chemical action that leads to weathering.

River Valley Formation

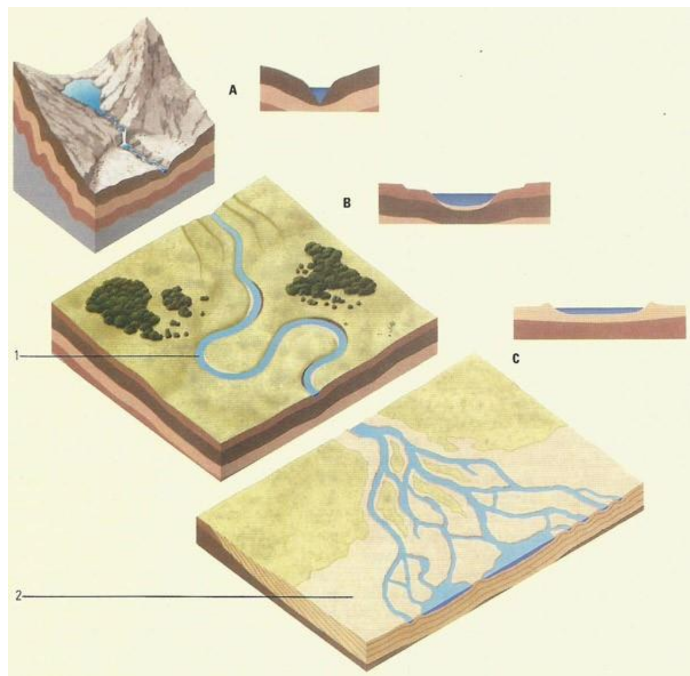
- The extended depression on ground through which a stream flows throughout its course is called a river valley.
- At different stages of the erosional cycle the valley acquires different profiles.
- At a young stage, the valley is deep, narrow with steep wall-like sides and a convex slope. The erosional 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 and because of recession of a waterfall. Most Himalayan rivers pass through deep gorges (at times more than 500 metres deep) before they descend to the plains.

- An extended form of 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** becomes prominent and the valley floor flattens out. The valley profile now becomes typically 'U' shaped with a broad base and a concave slope.





River course



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.

Maturity

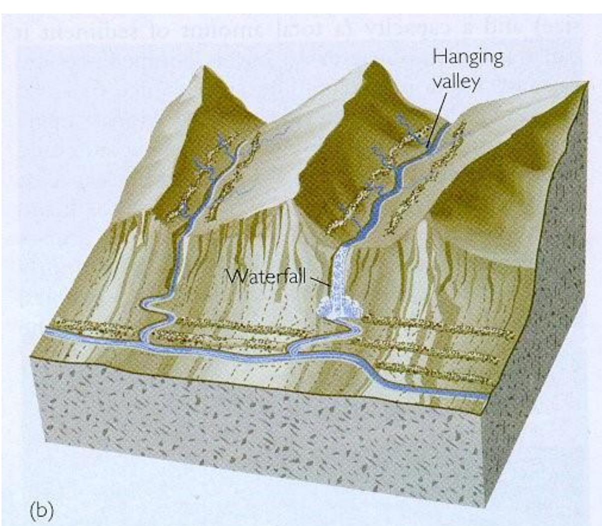
- Mature rivers (B) are lower-energy systems. Erosion takes place on the outside of bends, creating looping meanders in the soft alluvium of the river plain. Deposition occurs on the inside of bends and on the river bed.

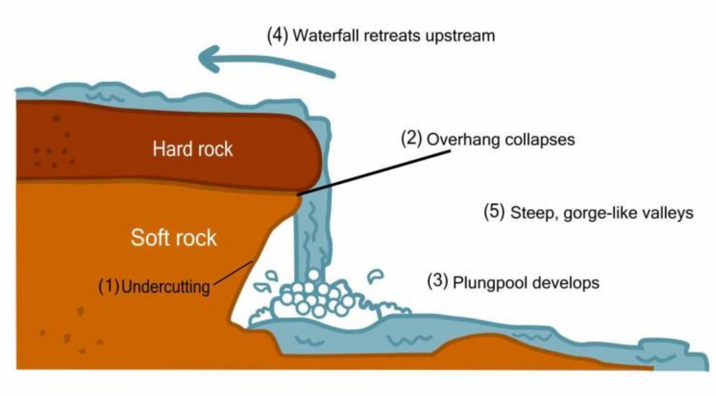
Old Age

- 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 islands and braiding 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.
- **Head ward 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.

Waterfalls

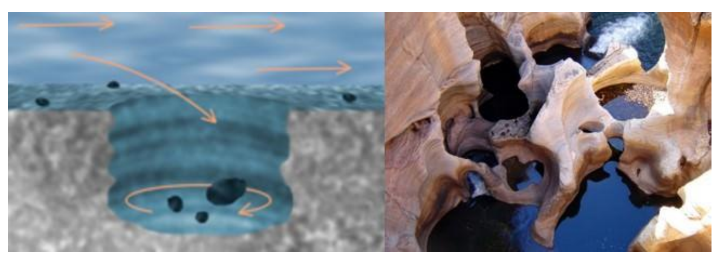
- A waterfall is simply the fall of an enormous volume of water from a great height.
- They are mostly seen in youth stage of river.
- Relative resistance of rocks, relative difference in topographic reliefs, fall in the sea level and related rejuvenation, earth movements etc. are responsible for the formation of waterfalls.
- For example, **Jog or Gersoppa falls on Sharavati** (a tributary of Cauveri) has a fall of 260 metres.





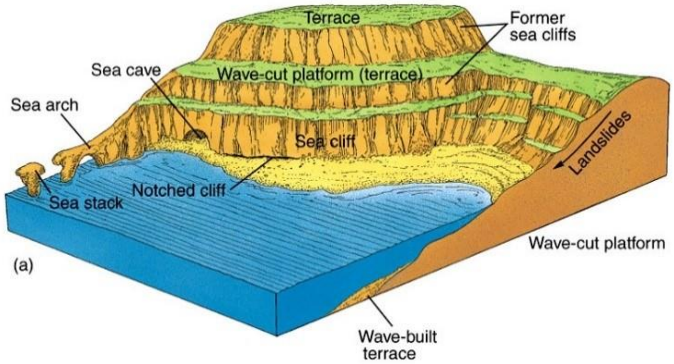
Pot Holes

- The kettle-like small depressions in the rocky beds of the river valleys are called pot holes which are usually cylindrical in shape.
- Potholing or pothole-drilling is the mechanism through which the grinding tools (fragments of rocks, e.g. boulders and angular rock fragments) when caught in the water eddies or swirling water start dancing in a circular manner and grind and drill the rock beds of the valleys like a drilling machine.
- They thus form small holes which are gradually enlarged by the repetition of the said mechanism. The potholes go on increasing in both diameter and depth.



Terraces

- 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) flood plains.



Gulleys/Rills

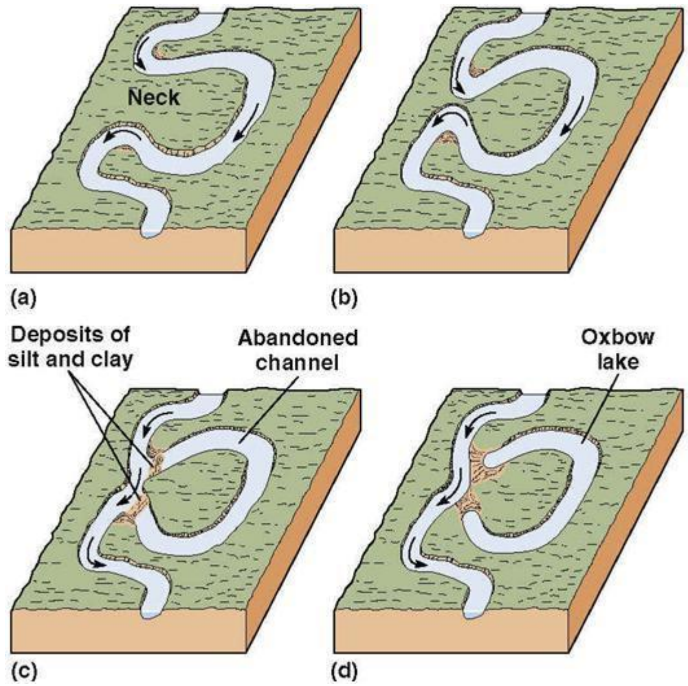
- Gulley is an incised water-worn channel, which is particularly common in semi-arid areas.
- It is formed when water from overland-flows down a slope, especially following heavy rainfall, is concentrated into rills, which merge and enlarge into a gulley.
- The **ravines of Chambal Valley** in Central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

Meanders

- 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.**
- Morphologically, the meanders may be wavy, horse-shoe type or ox-bow/ bracelet type.

Ox-Bow 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. These water bodies are converted into swamps in due course of time.
- In the Indo-Gangetic plains, southwards shifting of Ganga has left many ox-bow lakes to the north of the present course of the Ganga.



Peneplane (Or peneplain)

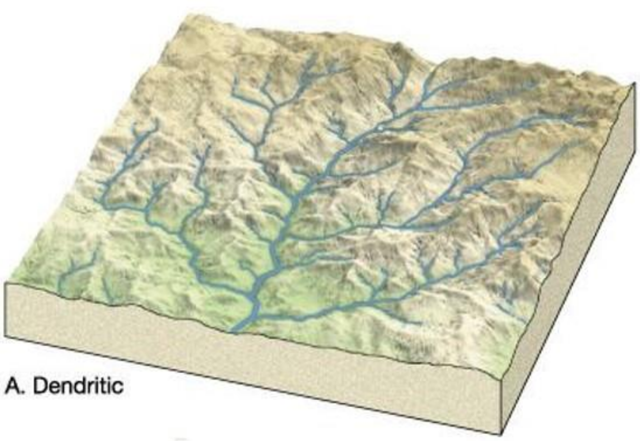
- This refers to an undulating featureless plain punctuated with low-lying residual hills of resistant rocks. It is considered to be an **end product of an erosional cycle**.
- Peneplain, gently **undulating (wave like)**, almost featureless plain that, in principle, would be produced by fluvial erosion that would, in the course of geologic time, reduce the land almost to baselevel (sea level), leaving so little gradient that essentially no more erosion could occur.

Drainage Patterns

- The typical shape of a river course as it completes its erosional cycle is referred to as the drainage pattern of a stream.
- A drainage pattern reflects the structure of basal rocks, resistance and strength, cracks or joints and tectonic irregularity, if any.

Dendric or Pinnate

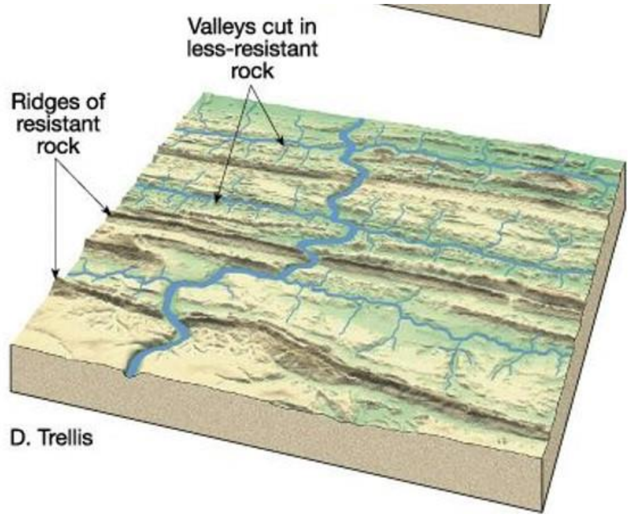
- This is an **irregular tree branch shaped** pattern.
- Examples: **Indus, Godavari, Mahanadi, Cauvery, Krishna**.



A. Dendritic

Trellis

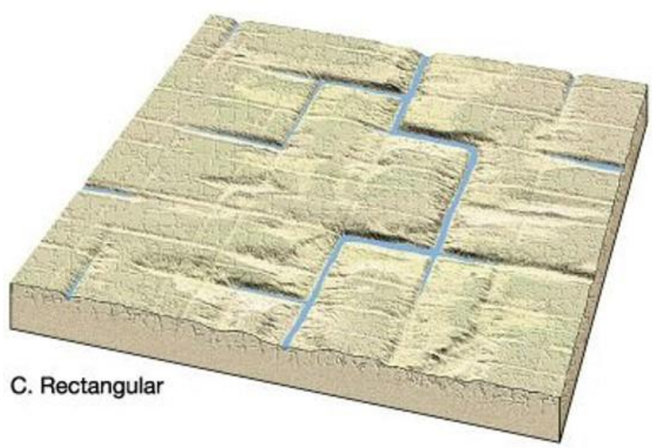
- In this type of pattern the short subsequent streams meet the main stream at **right angles**, and differential erosion through soft rocks paves the way for tributaries.
- Examples: Seine and its tributaries in Paris basin (France).



D. Trellis

Rectangular

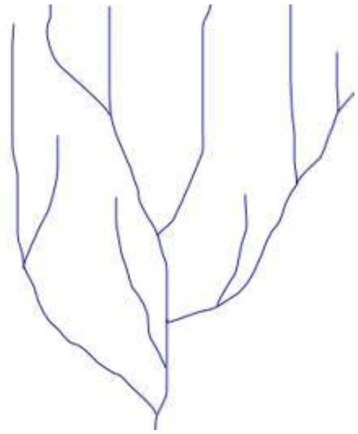
- The **main stream bends at right angles** and the tributaries join at right angles creating rectangular patterns.
- This pattern has a subsequent origin (subsequent drainage – you will study this in Indian drainage systems). Example: **Colorado river (USA).**



C. Rectangular

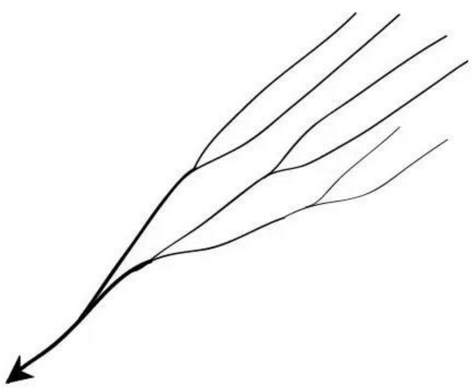
Angular

- The tributaries join the main stream at **acute angles**.
- This pattern is common in **Himalayan foothill regions.**



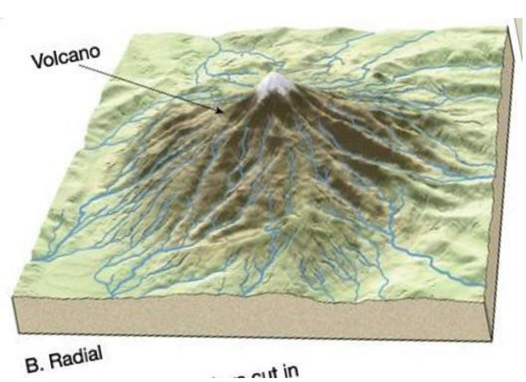
Parallel

- The tributaries seem to be running parallel to each other in a uniformly sloping region.
- Example: **rivers of lesser Himalayas**.



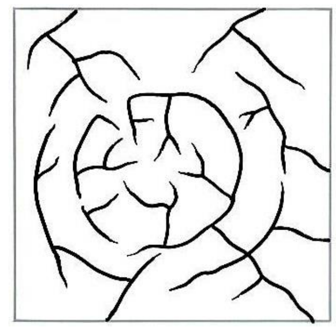
Radial

- The tributaries from a summit follow the slope downwards and drain down in all directions.
- Examples: **streams of Saurashtra region** and the Central French Plateau, Mt. Kilimanjaro etc..



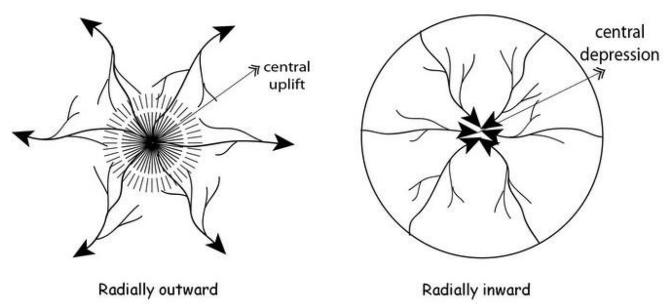
Annular

- When the upland has an outer soft stratum, the radial streams develop subsequent tributaries which try to follow a circular drainage around the summit.
- Example: Black Hill streams of South Dakota.



Centripetal

- In a low lying basin the streams converge from all sides.
- Examples: **streams of Ladakh, Tibet, and the Baghmati and its tributaries in Nepal**.



Fluvial Depositional Landforms are landforms created by the depositional activity of rivers.

Landforms and Cycle of Erosion

Fluvial landforms and Cycle of Erosion – Erosional Landforms [Previous Post: Fluvial Erosional Landforms – Drainage Patterns – River Valley] and Depositional Landforms [This Post].

- Glacial landforms and Cycle of Erosion
- Marine landforms and Cycle of Erosion
- Arid landforms and Cycle of Erosion
- Karst landforms and Cycle of Erosion

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.

Fluvial Depositional Landforms

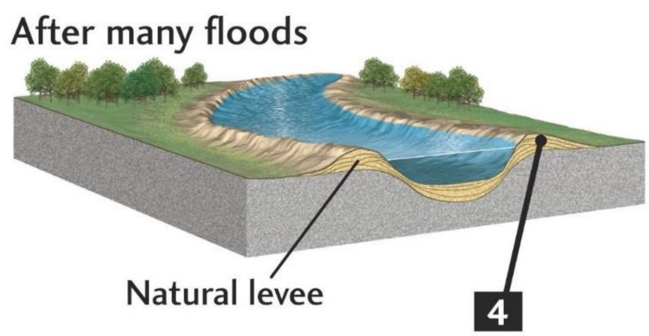
- The depositional action of a stream is influenced by stream velocity and the volume of river load.
- The decrease in stream velocity reduces the transporting power of the streams which are forced to leave some load to settle down.
- Increase in river load is effected through accelerated rate of erosion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

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.

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.
- These act as a natural protection against floods but a breach in a levee causes sudden floods in adjoining areas, as it happens in the case of the **Hwang Ho river of China**.



Delta

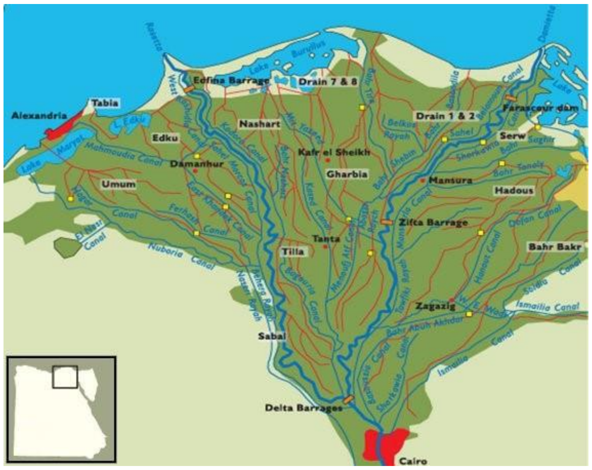
- A delta is a tract of alluvium at the mouth of a river where it deposits more material than can be carried away.
- The river gets divided into distributaries which may further divide and rejoin to form a network of channels.
- A delta is formed by a combination of two processes:

1. load-bearing capacity of a river is reduced as a result of the check to its speed as it enters a sea or lake, and
2. clay particles carried in suspension in the river **coagulate** in the presence of salt water and are deposited.

- 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.

Arcuate or Fan-shaped (Curved)

- This type of delta results when light depositions give rise to shallow, shifting distributaries and a general fan-shaped profile. Examples: **Nile, Ganga, Indus.**



Bird's Foot Delta (Elongated)

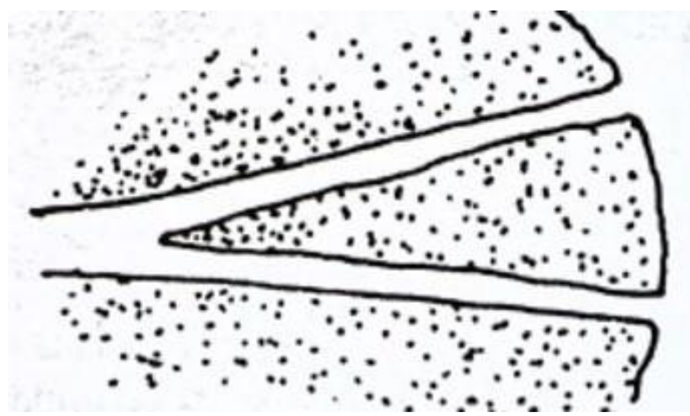
- This type of delta emerges when limestone sediment deposits do not allow downward seepage of water.
- The distributaries seem to be flowing over projections of these deposits which appear as a bird's foot.
- The currents and tides are weak in such areas and the number of distributaries lesser as compared to an arcuate delta. Example: **Mississippi river.**

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.
- These are **ideal sites for fisheries, ports and industries** because estuaries provide access to deep water, especially if protected from currents and tides. Example: **Hudson estuary.**

Cuspate Delta

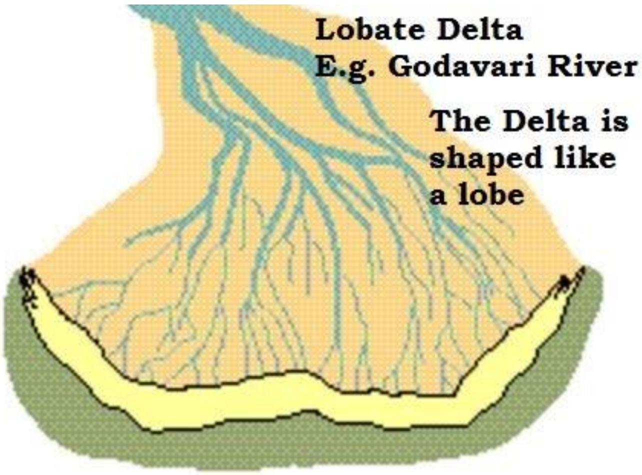
- This is a pointed delta formed generally along strong coasts and is subjected to strong wave action. There are very few or no distributaries in a cuspate delta.
- Example: Tiber river on west coast of Italy.



High-constructive deltas – Elongate and Lobate Delta

- Develops when fluvial action and depositional process dominate the system.
- Elongate delta is represented by the **bird-foot delta of the Mississippi River**.
- Lobate delta is represented by the Godavari River.

Lobate: Shaped like a lobe.



Godavari – Lobate

Krishna – Arcuate

Kaveri – Quadrilateral

Nile, Indus, Ganga-Brahmaputra – Arcuate

All the above are more or less the same kind of deltas.

- Both of these types have a large sediment supply that tend to disperse sediment along the shoreline.
- A lobate delta (a sub type of fan shaped delta) is formed if the river water is as dense as the seawater (precipitation or coagulation of river sediments occur immediately and hence the delta is not elongated).
- A bird-boot delta (elongated delta) is formed when the river water is lighter than sea water (precipitation or coagulation of river sediments can occur at a distance from shore and hence the delta is elongated).

High-destructive deltas

- Shoreline energy is high and much of the sediment delivered by the river is reworked by wave action or currents before it is finally deposited.
- Deltas formed by rivers such as the Nile and the Rhône have been classified as wave-dominated.
- In this class of high-destructive delta, sediment is finally deposited as arcuate sand barriers near the mouth of the river.

Karst Landforms and Cycle of Erosion

- 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.

Cavern

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

Arch/Natural Bridge

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

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.

Karst Window

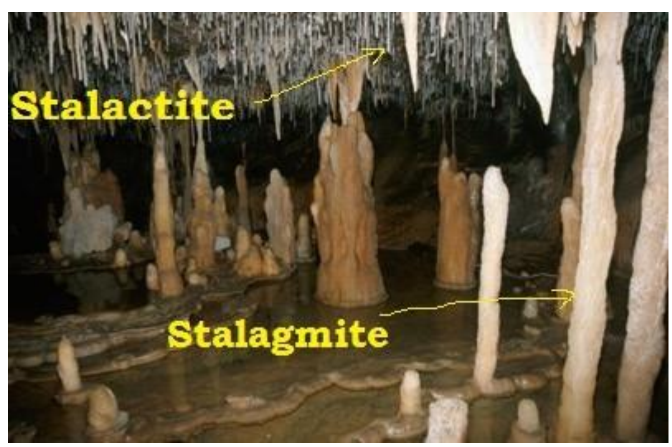
- When a number of adjoining sink holes collapse, they form an open, broad area called a karst window.

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.

Stalactite and Stalagmite

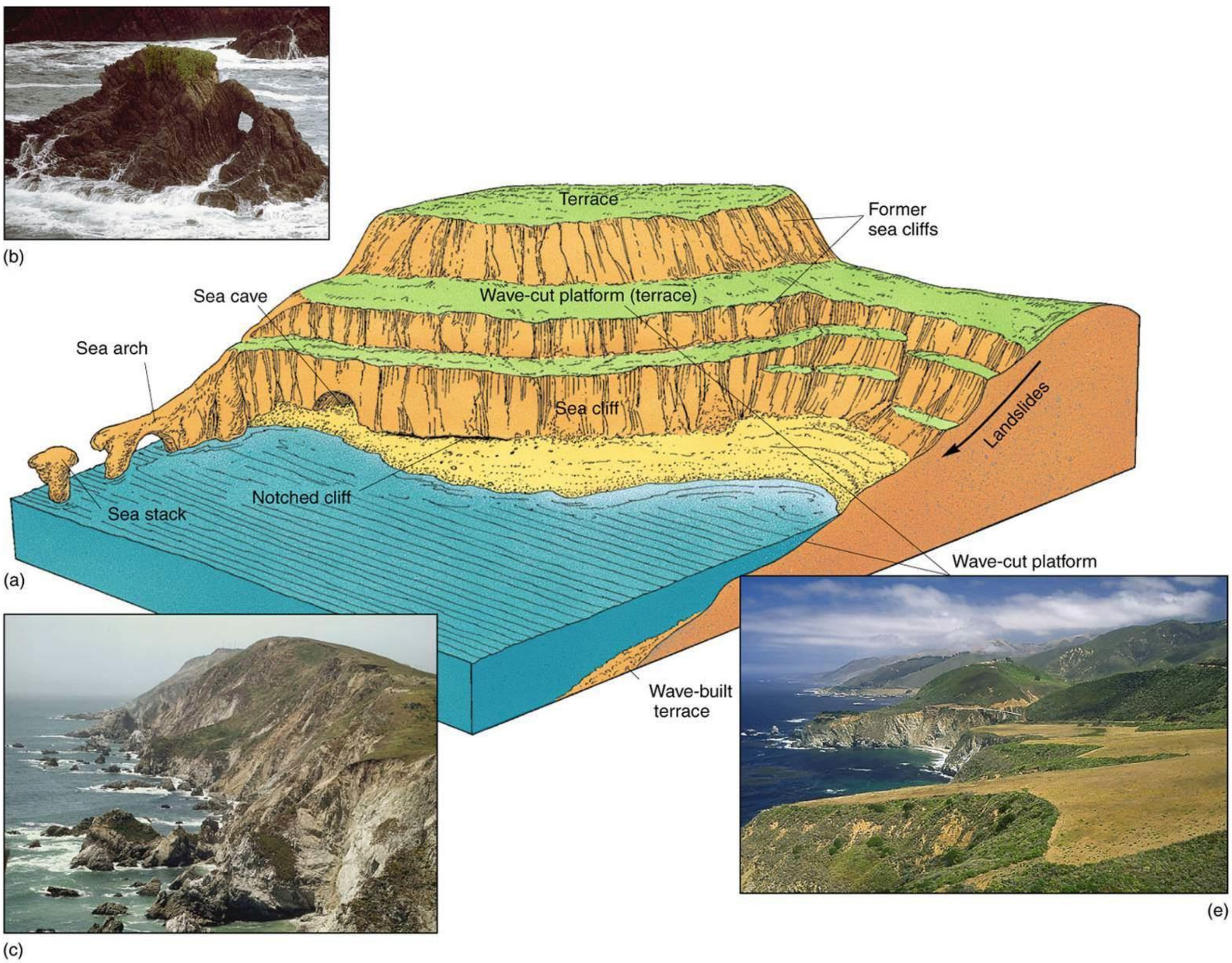
- The water containing limestone in solution, seeps through the roof in the form of a continuous chain of drops.
- A portion of the roof hangs on the roof and on evaporation of water, a small deposit of limestone is left behind contributing to the formation of a stalactite, growing downwards from the 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.



Marine Landforms and Cycle of Erosion

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

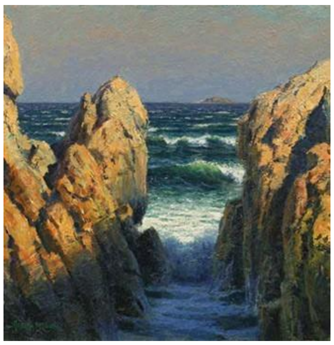
- The erosive work of the sea depends upon size and strength of waves, slope, height of the shore between low and high tides, shape of the coast, composition of rocks, depth of water, human activity etc.
- The wave pressure compresses the air trapped inside rock fissures, joints, faults, etc. forcing 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

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.

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.

Sea Cliff

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

Sea Caves

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

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.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.

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.

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.

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 Depositional Landforms

Beach

- This is the temporary covering of rock debris on or along a wave-cut platform.

Bar

- Currents and tidal currents deposit rock debris and sand along the coast at a distance from the shoreline.
- The resultant landforms which remain submerged are called bars.
- The enclosed water body so created is called a **lagoon.**

Barrier

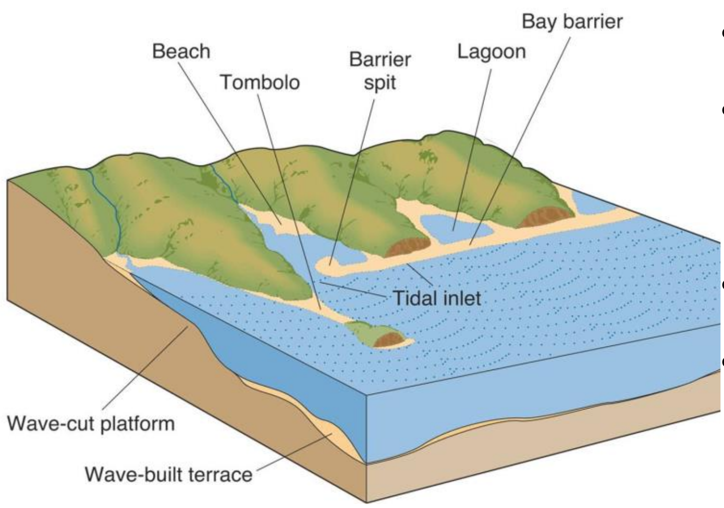
- It is the overwater counterpart of a bar.

Spit and Hook

- A spit is a projected deposition joined at one end to the headland, with the other end free in the sea.
- The mode of formation is similar to a bar or barrier.
- A shorter spit with one end curved towards the land is called a **hook.**

Tombolos

- Sometimes, islands are connected to each other by a bar called tombolo.



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:

1. Coastline of Emergence
2. Coastline of Submergence
3. Neutral coastline
4. Compound coastline
5. Fault coastline

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

Coastlines of Emergence

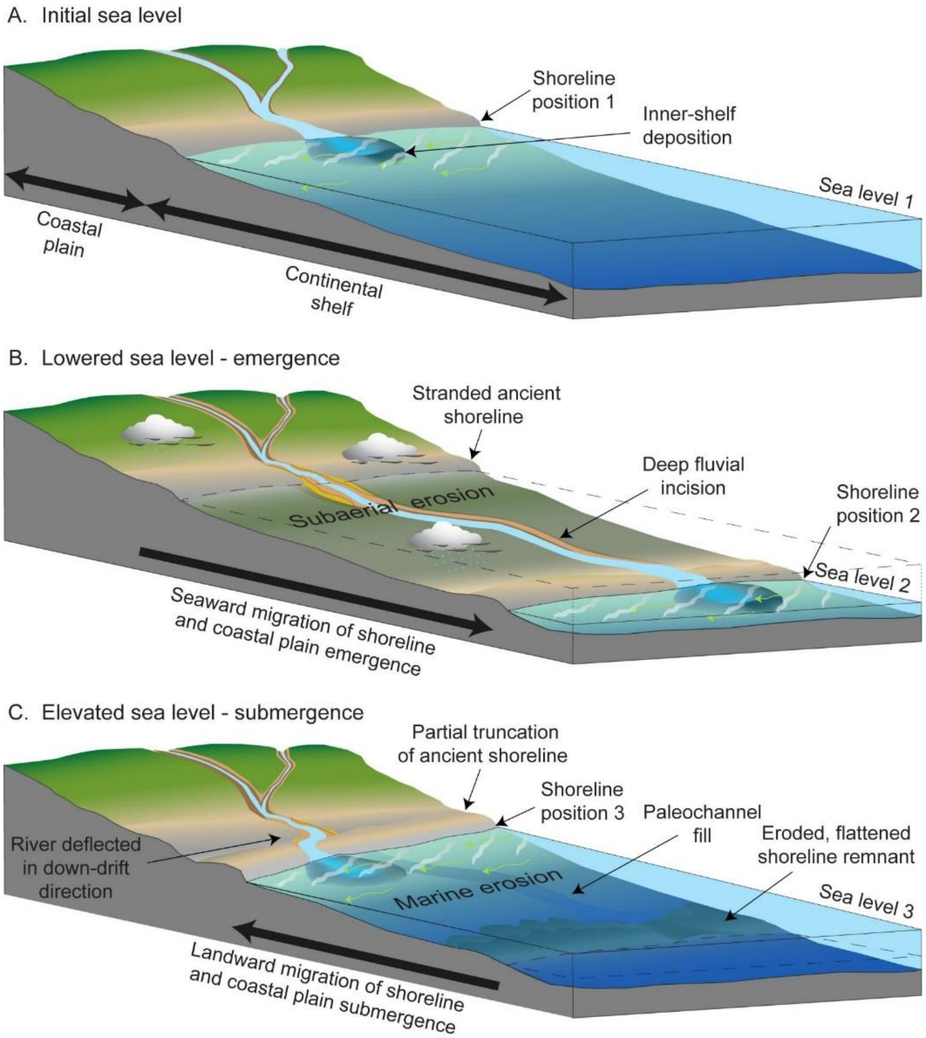
- These are formed either by an uplift of the land or by the lowering of the sea level.
- Bars, spits, lagoons, salt marshes, beaches, sea cliffs and arches are the typical features.
- The **east coast of India**, especially its south-eastern part **(Tamil Nadu coast)**, appears to be a **coast of emergence**.
- The **west coast of India**, on the other hand, is **both emergent and submergent**. The **northern portion of the coast is submerged** as a result of faulting and the southern portion, that is the **Kerala coast, is an example of an emergent coast**.
- Coramandal coast == Tamil Nadu Coast == Coastline of emergence
- Malabar coast == Kerala Coast == Coastline of emergence
- Konkan coast == Maharashtra and Goa Coast == Coastline of submergence.

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.

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.



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.

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.

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

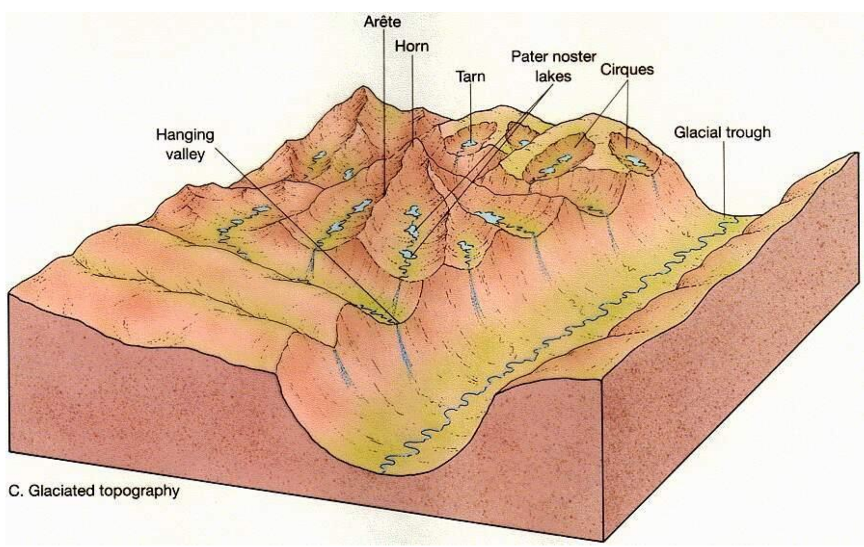
- Such coastlines are unusual features and result from the submergence of a downthrown block along a fault, such that the uplifted block has its steep side (or the faultline) standing against the sea forming a fault coastline.

Landforms and Cycle of Erosion

- Fluvial Erosional Landforms [Done]
- Fluvial Depositional Landforms [Previous Post]
- Glacial landforms and Cycle of Erosion [This Post]
- Marine landforms and Cycle of Erosion [Next Post]
- Arid landforms and Cycle of Erosion
- Karst landforms and Cycle of Erosion

Glacial Landforms and Cycle of Erosion

- A glacier is a moving mass of ice at speeds averaging few meters a day.
- Types of Glaciers: **continental glaciers, ice caps, piedmont glaciers and valley glaciers**.
- The continental glaciers are found in the Antarctica and in Greenland. The biggest continental ice sheet in **Iceland.**
- Ice caps are the covers of snow and ice on mountains from which the valley or mountain glaciers originate.
- The piedmont glaciers form a continuous ice sheet at the base of mountains as in southern Alaska.
- 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.
- The largest of Indian glaciers occur in the Karakoram range, viz. **Siachen (72 km),** while Gangotri in Uttar Pradesh (Himalayas) is 25.5 km long.
- A glacier is charged with **rock debris** which are used for erosional activity by moving ice.
- A glacier during its lifetime creates various landforms which may be classified into erosional and depositional landforms. Glacial Erosional Landforms



Cirque/Corrie

- Hollow basin cut into a mountain ridge.

- It has steep sided slope on three sides, an open end on one side and a flat bottom.
- When the ice melts, the cirque may develop into a **tarn lake.**

Glacial Trough

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

Hanging Valley

- 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**.
- A valley carved out by a small tributary glacier that joins with a valley carved out by a much larger glacier.

Arete

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

Horn

- Ridge that acquires a 'horn' shape when the glacial activity cuts it from **more than two sides.**

D-Fjord

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

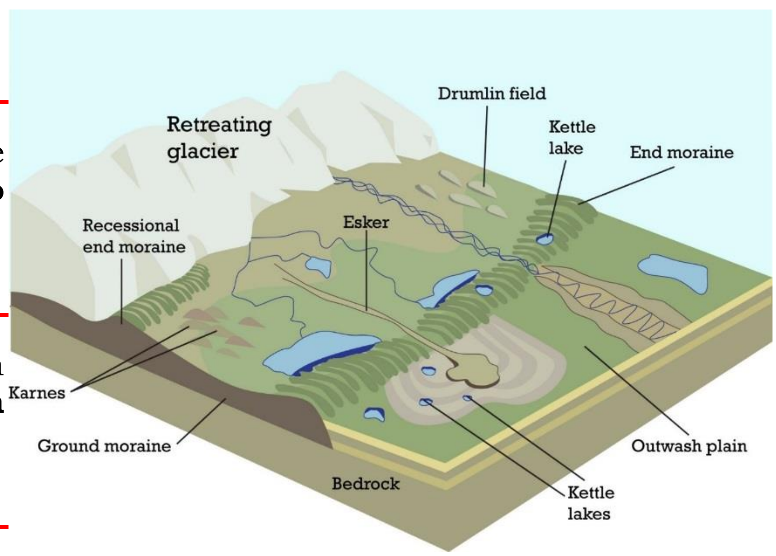
Glacial Depositional Landforms

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.

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.



Kame Terraces

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

Drumlin

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

Kettle Holes

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

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

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.

Maturity

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

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.

Arid Landforms and Cycle of Erosion

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

Erosional Arid Landforms

Water Eroded Arid Landforms

Rill

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

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.

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.

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.**

Bolsons

- The intermontane basins in dry regions are generally known as bolsons.

Playas

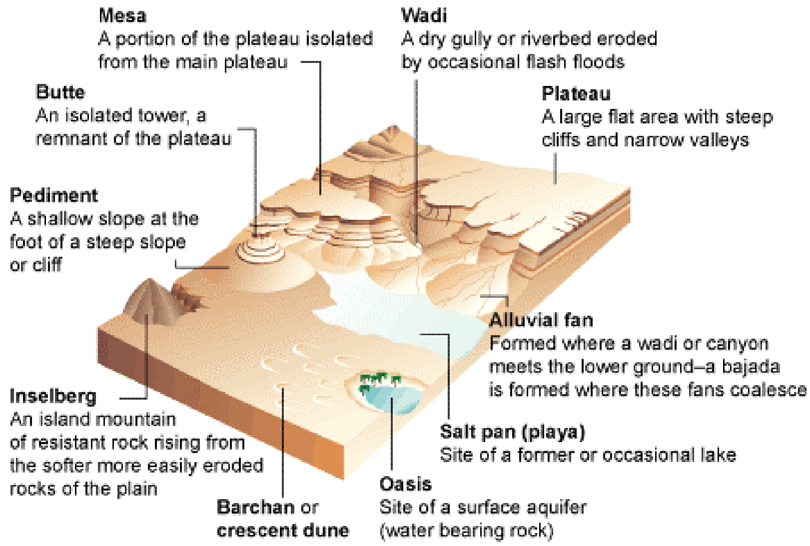
- Three unique landforms viz. pediments, bajadas and playas are typically found in bolsons.
- Small streams flow into bolsons, where water is accumulated. These **temporary lakes are called playas.**
- After the evaporation of water, salt-covered playas are called salinas.

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.

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.

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.

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.

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.

Demoiselles

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

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.

Yardangs

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

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.

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).

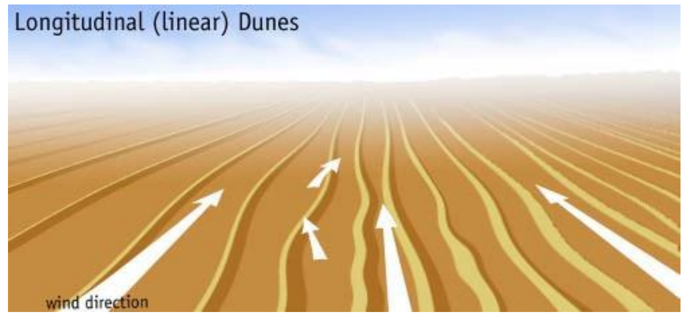
Sand dunes

- 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:

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.



Transverse dunes

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

Barchans

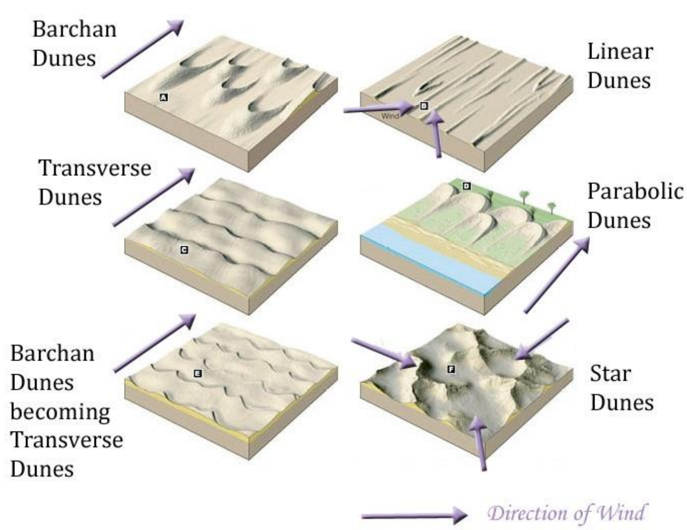
- Crescent shaped dunes. The windward side is convex whereas the leeward side is concave and steep.

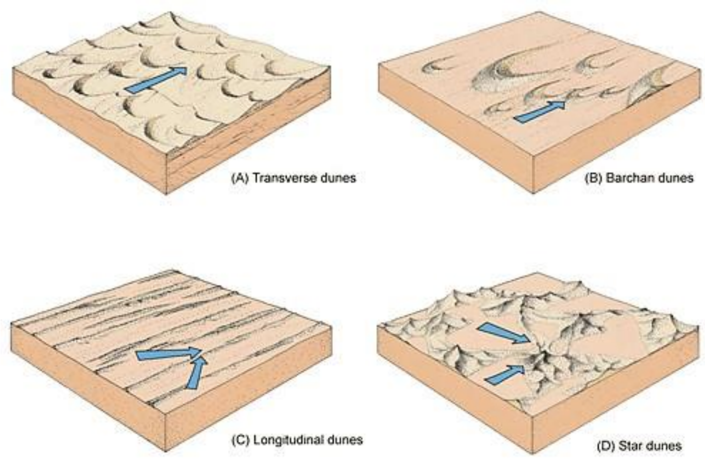
Parabolic dunes

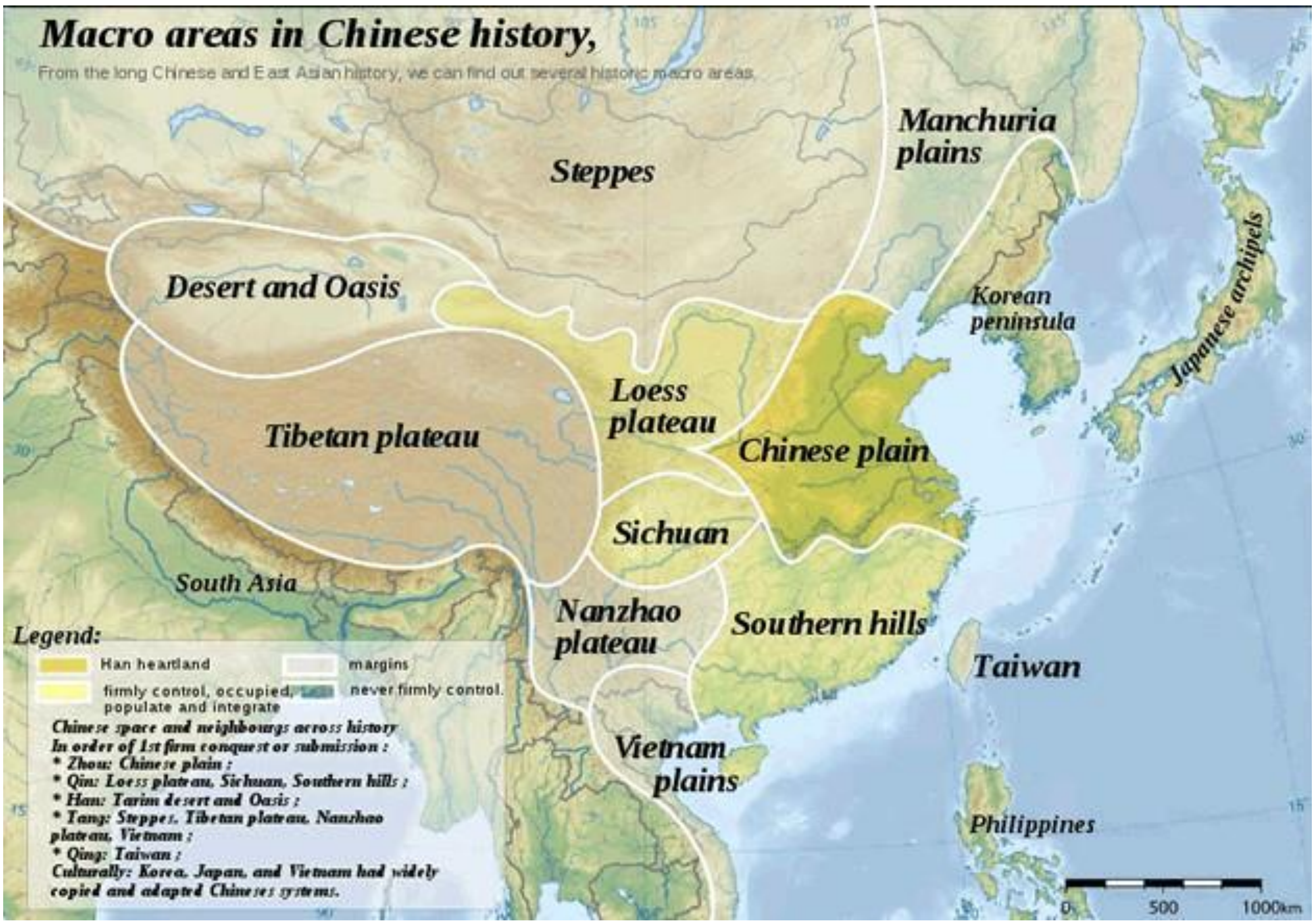
- They are U-shaped and are much longer and narrower than barchans.

Star dunes

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







Loess

- 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**.
- The thickest loess deposits are near the **Missouri River** in the U.S. state of Iowa and along the **Yellow River in China**.
- 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.

In this post: Lakes – Classification of Lakes.

Next Post: Important Lakes.

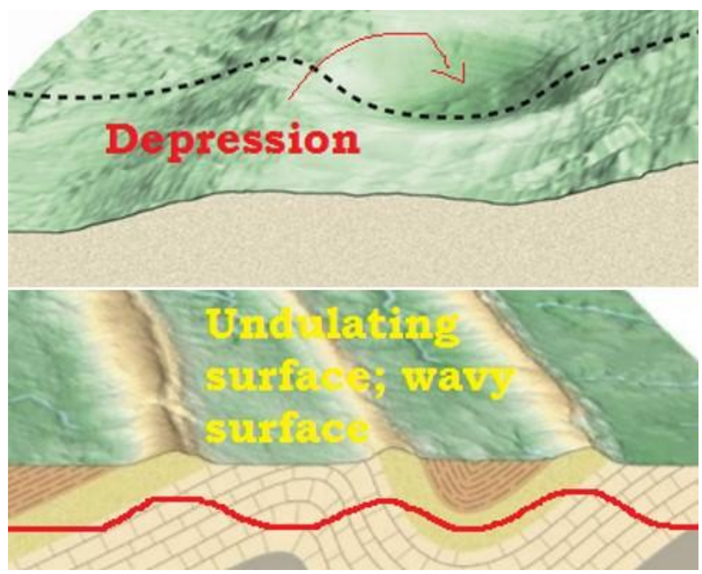
Lakes

- A lake is a body of water of considerable size, localized in a basin, that is surrounded by land apart from a river or other outlet that serves to feed or drain the lake.
- Lakes lie on land and are not part of the ocean, and therefore are distinct from lagoons, and are also larger and deeper than ponds.
- Natural lakes are generally found in mountainous areas, rift zones, and areas with ongoing glaciation.
- Most lakes have at least one natural outflow in the form of a river or stream, which maintain a lake's average level by allowing the drainage of excess water
- Other lakes are found in endorheic basins. Some lakes do not have a natural outflow and lose water solely by evaporation or underground seepage or both. They are termed **endorheic lakes**.
- The majority of lakes on Earth are fresh water, and most lie in the Northern Hemisphere at higher latitudes. Canada, Finland and Siberia contain most of the fresh water lakes.

Classification of Lakes

Temporary lakes

- Lakes may exist temporarily filling up the small depressions of undulating ground after a heavy shower.
- In this kind of lakes, Evaporation > Precipitation.
- Example: Small lakes of deserts.



Permanent lakes

- In this kind of lakes, Evaporation < Precipitation.
- These lakes are deep and carry more water than could ever be evaporated.
- Example: **Great Lakes of North America, East African Rift Lakes**.

Divergent Boundary – African Rift System Formation

Fresh water lakes

- Most of the lakes in the world are fresh-water lakes fed by rivers and with out-flowing streams e.g. Great Lakes of North America.

Saline lakes

- Salt lakes (also called saline lakes) can form where there is no natural outlet or where the water evaporates rapidly and the drainage surface of the water table has a higher-than-normal salt content.
- Because of the intense evaporation (negative freshwater balance == more water is lost in evaporation than gained from rivers) these lakes are saline.
- Examples of salt lakes include **Great Salt Lake**, the **Aral Sea** and the **Dead Sea**.
- For example the **Dead Sea** has a salinity (salt content) of 250 parts per thousand, and the **Great Salt Lake of Utah, U.S.A**. has a salinity of 220 parts per thousand.
- **Playas or salt lakes**, are a common feature of deserts (recall desert landforms).

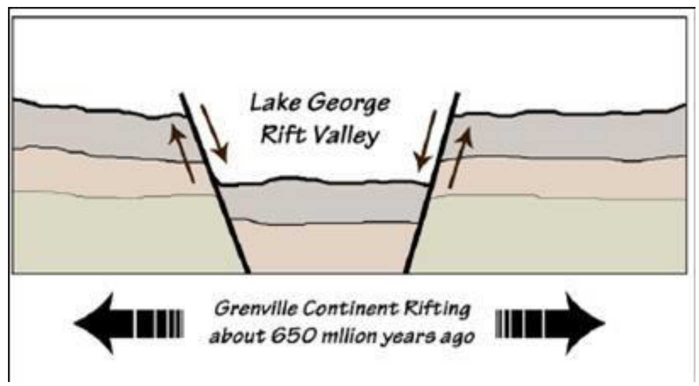
Lakes Formed by Earth Movement

Tectonic lakes

- Due to the warping (simple deformation), subsidence (sliding downwards), bending and fracturing (splitting) of the earth's crust, tectonic depressions occur. (We have studied all these terms in previous posts)
- Such depressions give rise to lakes of immense sizes and depths.
- They include **Lake Titicaca**, and the **Caspian Sea.**

Rift valley lakes

- A rift valley is formed when two blocks of earth move apart letting the 'in between' block slide downwards. Or, it's a sunken land between two parallel faults.
- Rift valleys are deep, narrow and elongated. Hence the lakes formed along rift valleys are also deep, narrow and very long.
- Water collects in troughs (Valley in the rift) and their floors are often below sea level.
- The best known example is the **East African Rift Valley** which runs through Zambia, Malawi, Tanzania, Kenya and Ethiopia, and extends along the Red Sea to Israel and Jordan over a total distance of 3,000 miles.
- It includes such lakes as **Lakes Tanganyika**, **Malawi, Rudolf, Edward, Albert**, as well as the **Dead Sea** 1,286 feet below mean sea level, the **world's lowest lake**.



Lakes Formed by Glaciation

Cirque lakes or tarns

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

Rock-hollow lakes

- The advance and retreat of glaciers can scrape depressions in the surface where water accumulates; such lakes are common in Scandinavia, Patagonia, Siberia and Canada.
- These are formed by ice-scouring (eroding) when ice sheets scoop out (dig) hollows on the surface.

- Such lakes of glacial origin are abundant in Finland - Land of Lakes. It is said that there are over 35,000 glacial lakes in Finland.

Lakes due to morainic damming of valleys

- Valley glaciers often deposit morainic debris across a valley so that lakes are formed when water accumulates behind the barrier.

Lakes Formed by Volcanic Activity

Crater and caldera lakes

- During a volcanic explosion the top of the cone may be blown off leaving behind a natural hollow called a crater.
- This may be enlarged by subsidence into a caldera.
- In dormant or extinct volcanoes, rain falls straight into the crater or caldera which has no superficial outlet and forms a crater or caldera lake.
- Examples: **Lonar in Maharashtra** and **Krakatao in Indonesia.**

Others are Lava-blocked lakes and Lakes due to subsidence of a volcanic land surface.

Lakes Formed by Erosion

Karst lakes

- The solvent action of rain-water on limestone carves out solution hollows. When these become clogged with debris lakes may form in them.
- The collapse of limestone roofs of underground caverns may result in the exposure of long, narrow- lakes that were once underground.

Wind-deflated lakes

- The winds in deserts creates hollows. These may reach ground water which seeps out forming small, shallow lakes. Excessive evaporation causes these to become salt lakes and playas. Example: **Great Basin of Utah, U.S.A.**

Lakes Formed by Deposition

Lakes due to river deposits

- Ox-bow lake, e.g. those that occur on the flood-plains of Lower Mississippi, Lower Ganges etc..

Lakes due to Marine deposits

- Also called Lagoons.
- Example: Lake Chilka

Lakes due to damming of water

- Lakes formed by these processes are also known as barrier lakes. Landslides, avalanches may block valleys so that rivers are dammed. Such lakes are short-lived.
- Example: Lakes that are formed in Shiwaliks (Outer Himalayas). Dehradun (all Duns) were lakes few centuries ago.

Man-made lakes

- Besides the natural lakes, man has now created artificial lakes by erecting a concrete dam across a river valley so that the river water can be kept back to form reservoirs.
- Example: Lake Mead above the Hoover Dam on the Colorado River, U.S.A.
- Man’s mining activities, e.g. tin mining in West Malaysia, have created numerous

lakes. Inland fish culture has necessitated the creation of many fishing-lakes.

Lakes and Man

- In countries where they are found in abundance, such as Finland, Canada, U.S.A., Sweden and the East African states, lakes are used as inland waterways.

Means of communication

- Large lakes like the Great Lakes of North America provide a cheap and convenient form of transport for heavy and bulky goods such as coal, iron, machinery, grains and timber.
- **The Great Lakes-St. Lawrence waterways** penetrate more than 1,700 miles into the interior. They are thus used as the chief arteries of commerce.

Economic and industrial development

- The Great Lakes-St. Lawrence waterways were responsible for the development of the interior wheat farms and lakeside industries.

Water storage

- Example: Kolleru lake in Andhra Pradesh.

Hydro-electric power generation

- Artificial lakes like Hirakud.

Agricultural purposes

- Many dams are built across artificial lakes.
- Bhakra Nangal Dam. Its reservoir, known as the **"Gobind Sagar Lake"** and Hirakud Dam (Madhya Pradesh) on the Mahanadi in India.

Regulating river flows

- **Hoover Dam on the River Colorado** and the **Bhakra and Nangal Dams on the Sutlej** in India.
- The Hirakud dam was originally conceived as a flood control measure. But the project is criticized for doing more damage than good.

Moderation of climate

- Land and see breeze (we will see this in future posts).

Source of food

- Many large lakes have important supplies of protein food in the form of freshwater fish. Sturgeon is commercially caught in the Caspian Sea, salmon and sea trout in the Great Lakes.

Source of minerals

- Salt lakes provide valuable rock salts. In the Dead Sea, the highly saline water is being evaporated and produces common salt. **Borax** is mined in the salt lakes of the Mojave Desert.

Tourist attraction and health resorts

- Lake Chilka, Leh, Dead Sea etc..

No lake is permanent over geologic time

- Lakes are only temporary features of the earth's crust; they will eventually be eliminated by the double process of draining and silting up.
- The process of lake elimination may not be completed within our span of life, it takes place relatively quickly in terms of geological time.

Important Lakes on Earth

Note 1: ***Black Sea is not a lake*** *since* ***Bosporus*** *and* ***Dardanelles Straits*** *connect it to the Mediterranean Sea. Many big rivers fall into the Black Sea, making the salinity of its surface water half that of the ocean: 17‰.*

Note 2: ***Caspian Sea*** *and* ***Dead Sea*** *are lakes.* ***The surface and shores of the***

Dead Sea are 423 metres below sea level, making it Earth's lowest elevation on land.

Note 3: *While writing facts about lakes, people ignore Caspian Sea because for them it is too big to be considered a lake. But it is still a lake.*

Note 4: *Just like everybody else, even I have ignored Caspian Sea while stating the below facts.*

Lake Baikal [Deepest]

- Located in Siberia, Russia.
- The **deepest lake in the world** [1,637 metres deep]
- It is the world's largest lake by volume.
- It is the second longest.

Lake Tanganyika [Longest]

- The **longest lake in the world**. [660 kilometres long]
- It is also the second largest by volume.
- It is the second deepest lake in the world, after lake Baikal.

World's Highest and Lowest Lakes

- The world's highest lake, if size is not a criterion, may be the **crater lake of Ojos del Salado**, at 6,390 metres. It is in Andes.
- The highest large lake in the world is the **Pumoyong Tso (Pumuoyong Tso)**, in the Tibet Autonomous Region of China. [5,018 metres above sea level]
- The **world's highest commercially navigable lake** is **Lake Titicaca** in Peru and Bolivia border at 3,812 m. It is also the **largest lake in South America**.
- The world's lowest lake is the Dead Sea, bordering Israel and Jordan at 418 metres below sea level. It is also one of the lakes with highest salt concentration.

The largest lakes (surface area) by continent

- **Australia – Lake Eyre** (salt lake)
- **Africa – Lake Victoria**, also the third-largest freshwater lake on Earth. It is one of the Great Lakes of Africa.
- **Antarctica – Lake Vostok** (subglacial)
- **Asia – Lake Baikal** (if the Caspian Sea is considered a lake, it is the largest in Eurasia, but is divided between the two geographic continents)
- **Europe – Lake Ladoga**, followed by Lake Onega, both located in northwestern Russia.
- **North America – Lake Superior**.

- **South America – Lake Titicaca**, which is also the highest navigable body of water on Earth at 3,812 metres above sea level. The much larger Lake Maracaibo is a contiguous body of water with the sea, so it is ignored. ,

Great Lakes

- Great Lakes of North America are a series of interconnected freshwater lakes which connect to the Atlantic Ocean through the **Saint Lawrence Seaway**.
- Consisting of Lakes **Superior, Michigan, Huron, Erie, and Ontario** [in the order of west to east]. **Superior, Huron, Michigan, Erie, and Ontario** [In the order of largest to smallest].
- Lake Superior is the **largest continental lake** in the world by area, and Lake **Michigan is the largest lake that is entirely within one country**.

Shipping

- The Great Lakes are today used as a major water transport corridor for bulk goods.
- The Great Lakes Waterway connects all the lakes; the smaller **Saint Lawrence Seaway** connects the lakes to the Atlantic oceans.

Dead Sea

- Also called the Salt Sea.
- Lake bordering Jordan to the east, and Palestine and Israel to the west.
- It Earth's lowest elevation on land.

Aral Sea

- It was a lake lying between Kazakhstan in the north and Uzbekistan, in the south.
- Aral Sea has been steadily shrinking since the 1960s after the rivers that fed it were diverted by Soviet irrigation projects.

The Aral Sea in 1989 (left) and 2008 (right)

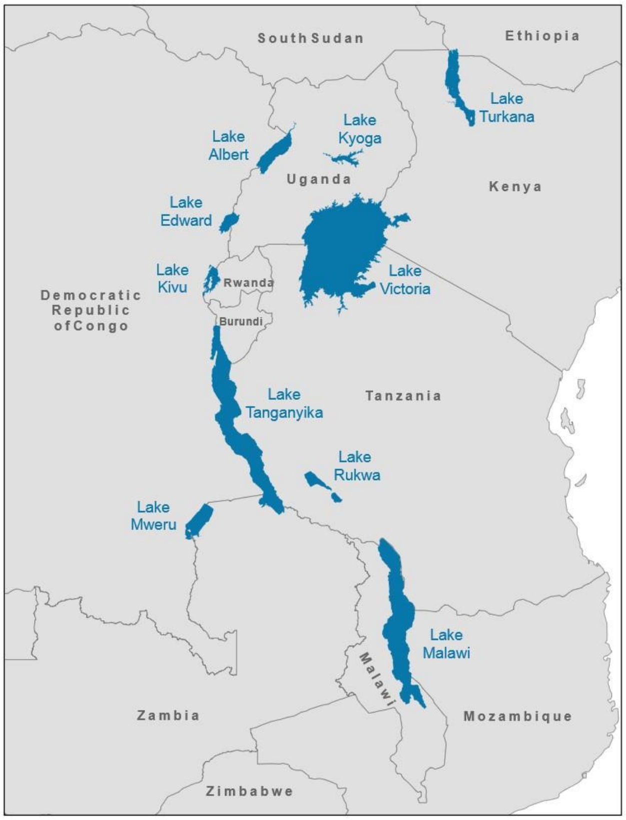
African Great Lakes

- Series of lakes constituting the part of the Rift Valley lakes in and around the East African Rift.
- They include Lake Victoria, the second largest fresh water lake in the world, and Lake Tanganyika, the world's second largest in volume as well as the second deepest.

Largest Lakes by Surface Area

1. Caspian Sea - Asia

2. Lake Superior - North America
3. Lake Victoria - Africa
4. Lake Huron - North America
5. Lake Michigan - North America



Largest Lakes by Volume

1. Baikal - Asia
2. Tanganyika - Africa
3. Superior - North America

Deepest Lakes in the World

1. Lake Baikal - Asia
2. Lake Tanganyika
3. Caspian Sea

This post: Plateau – Types – Major Plateaus of The World.

Previous Post:

Plateau

- A plateau is a flat-topped table land.
- Plateaus occur in every continent and take up a **third of the Earths land**.
- They are one of the four major landforms, along with mountains, plains, and hills.

- Plateaus, like mountains may be young or old. The Deccan plateau in India is one of the oldest plateaus.
- Valleys form when river water cuts through the plateau. The Columbia Plateau, between the Cascade and Rocky mountains in the northwestern United States, is cut through by the Columbia River.
- Sometimes, a plateau is so eroded that it is broken up into smaller raised sections called **outliers.** Many outlier plateaus are composed of very old, dense rock formations. Iron ore and coal often are found in plateau outliers.
- Plateaus are very useful because they are rich in mineral deposits. As a result, many of the mining areas in the world are located in the plateau areas.

Model question on Plateaus

Plateaus are of great economic significance. Comment with reference to India And World.

- The plateaus are famous for minerals. The plateau of France [Massif Central], the Deccan plateau of India, Katanga plateau of Congo [Copper mines], Western Australian plateau [Kimberly Plateau – Diamond mines] and Brazilian plateau [Brazilian Highlands] are very good sources of minerals. Iron, copper, gold, diamonds, Manganese, coal, etc., are found in these plateaus.
- East African plateau is famous for gold and diamond mining.

- In India huge reserves of iron, coal and manganese are found in the Chotanagpur plateau.
- In the plateau areas, there may be several waterfalls as the river falls from a great height. In India, the **Hundru Falls** in the **Chotanagpur plateau** on the river **Subarnarekha** and the **Jog Falls in Karnataka** are examples of such waterfalls. These sites are ideal for hydro-electric power generation. **Angel falls** in Venezuela is also a waterfall that descends down a plateau.

  [Plateaus are not very useful from the point of view of agriculture. The hard rocks on plateaus cannot form fertile soil but agricultural activities are promoted where lava soils have developed. It is difficult to dig wells and canals in plateaus. This hampers irrigation.]

- The lava plateaus like Deccan traps are rich in black soil that is fertile and good for cultivation. Example: Maharashtra has good cotton growing soils called **regurs**.
- Loess plateau in China has very fertile soils that are good for many kind of crops.
- Many plateaus have scenic spots and are of great attraction to tourists. (Grand Canyon, USA, many waterfalls)

Plateau Formation

- Tectonic plateaus are formed from processes that create mountain ranges – **volcanism (Deccan Plateau)**, crustal shortening (thrusting of one block of crust over another, and folding occurs. Example: **Tibet**), and thermal expansion **(Ethiopian Highlands)**.

Thermal expansion

- Thermal expansion of the lithosphere means the replacement of cold mantle lithosphere by hot asthenosphere).
- Those caused by thermal expansion of the lithosphere are usually associated with hot spots. The **Yellowstone Plateau in the United States**, the **Massif Central in France**, and the **Ethiopian Plateau in Africa** are prominent examples.
- When the lithosphere underlying a broad area is heated rapidly – e.g., by an upwelling of hot material in the underlying asthenosphere – the consequent warming and thermal expansion of the uppermost mantle causes an uplift of the overlying surface. The **high plateaus of East Africa and Ethiopia** were formed this way.

Crustal shortening

- The great heights of some plateaus, such as the Plateau of Tibet is due to **crustal shortening.**
- Crustal shortening, which thickens the crust as described above, has created high mountains along what are now the margins of such plateaus.
- Plateaus that were formed by crustal shortening and internal drainage lie within major mountain belts and generally in arid climates. They can be found in North Africa, Turkey, Iran, and Tibet, where the African, Arabian, and Indian continental masses have collided with the Eurasian continent.

Volcanic Flood Basalts - Traps

- A third type of plateau can form where extensive lava flows (called **flood basalts or traps**) and volcanic ash bury preexisting terrain, as exemplified by the **Columbia Plateau** in the northwestern United States, **Deccan Traps** of peninsular India, **Laurentian plateau or The Canadian Shield** and the **Siberian Traps of Russia**.
- Volcanic plateaus are commonly associated with eruptions that occurred during the Cenozoic or Mesozoic.
- Eruptions on the scale needed to produce volcanic plateaus are rare, and none seems to have taken place in recent time.
- The volcanism involved in such situations is commonly associated with hot spots. The lavas and ash are generally carried long distances from their sources, so that

the topography is not dominated by volcanoes or volcanic centers.

- The thickness of the volcanic rock can be tens to even hundreds of metres, and the top surface of flood basalts is typically very flat but often with sharply incised canyons and valleys.
- The volcanic eruptions that produce lava plateaus tend to be associated with hot spots. For example, the basalts of the Deccan Traps, which cover the Deccan plateau in India, were erupted 60–65 million years ago when India lay in the Southern Hemisphere, probably over the same hot spot that presently underlies the volcanic island of Reunion.
- In North America the Columbia River basalts may have been ejected over the same hot spot that underlies the Yellowstone area today. Lava plateaus of the scale of those three are not common features on Earth.

Others

- Some plateaus, like the Colorado Plateau, the Ordos Plateau in northern China, or the East African Highlands, do not seem to be related to hot spots or to vigorous upwelling in the asthenosphere but appear to be underlain by unusually hot material. The reason for localized heating beneath such areas is poorly understood, and thus an explanation for the distribution of plateaus of that type is not known.
- There are some plateaus whose origin is not known. Those of the Iberian Peninsula and north-central Mexico exhibit a topography that is largely high and relatively flat.

Plateau Types

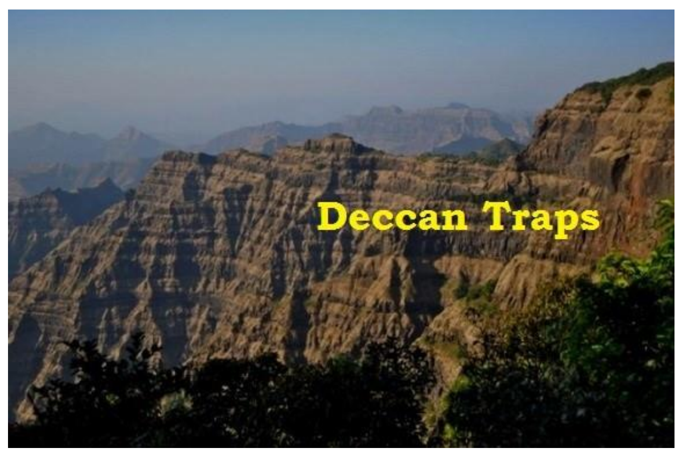
- There are two kinds of plateaus: **dissected plateaus** and **volcanic plateaus**.

Dissected plateau

- A dissected plateau forms as a result of upward movement in the Earth's crust.
- The uplift is caused by the slow collision of tectonic plates. The **Colorado Plateau**, in the western United States, Tibetan plateau etc. are examples.

Volcanic plateau

- A volcanic plateau is formed by numerous small volcanic eruptions that slowly build up over time, forming a plateau from the resulting lava flows.
- The **Columbia Plateau** in the northwestern United States of America and **Deccan Traps** are two such plateaus.



Others

- **Intermontane plateaus** are the highest in the world, bordered by mountains. The **Tibetan Plateau** is one such plateau.
- **Continental plateaus** are bordered on all sides by the plains or seas, forming away from mountains.

Major plateaus of the World

Tibetan Plateau

- **Highest and largest plateau** in the world and hence called the **'roof of the world'.**
- Formed due to collision of the Indo-Australian and Eurasian tectonic plates.
- The plateau is sufficiently high enough to reverse the Hadley cell convection cycles and to drive the monsoons of India towards the south. [We will learn this in future posts]
- It covers most of the Autonomous Tibetan Region, Qinghai Province of Western China, and a part of Ladakh in Jammu and Kashmir.
- It is surrounded by mountains to the south by the Himalayan Range, to the northeast by the **Kunlun Range**, and to the west by the **Karakoram Range**.

Columbia – Snake Plateau

- River Columbia and its tributary Snake meet in this plateau.
- It is bordered by the **Cascade Range** and **Rocky Mountains** and divided by the **Columbia River.**
- This plateau has been formed as the result of volcanic eruptions with a consequent coating of **basalt lava (Flood Basalt Plateau).**

Colorado Plateau

- It is lying to western part of U.S.A. It is the largest plateau in America.
- It is divided by the **Colorado River** and the **Grand Canyon**.
- This plateau is an example of intermontane plateau. Mesas and buttes are found here at many places [Arid Landforms].
- The plateau is known for the groundwater which is under positive pressure and causes the emergence of springs called **Artesian wells**.

Deccan Plateau

- Deccan Plateau is a large plateau which forms most of the southern part of India.
- It is bordered by two mountain ranges, the Western Ghats and the Eastern Ghats.
- The plateau includes the Deccan Traps which is the **largest volcanic feature on Earth**.
- Made of multiple basalt layers or lava flows, the Deccan Traps covers 500,000 square kilometers in area.
- The Deccan Traps are known for containing some unique fossils.
- The Deccan is rich in minerals. Primary mineral ores found in this region are mica

and iron ore in the Chotanagpur region, and diamonds, gold and other metals in the Golconda region.

Kimberley Plateau

- Lies in the northern part of Australia.
- This plateau is made of volcanic eruption.
- Many minerals like iron, gold, lead, zinc, silver and diamond are found here.
- Diamond is also found here.

Katanga Plateau

- It is lying in Congo.
- It is famous for **copper production**.
- Other minerals like Cobalt, Uranium, Zinc, Silver, Gold and Tin are also mined here.

Mascarene Plateau

- Plateaus also form in the ocean, such as the Mascarene Plateau in the Indian Ocean.
- It extends between the Seychelles and Mauritius Islands.

Laurentian Plateau

- Lying in the eastern part of Canada, it is a part of Canadian Shield.
- Fine quality of iron-ore is found here.

Mexican Plateau

- It is called as 'Mineral Store'. Different types of metallic minerals like silver, copper etc. are obtained from here.
- World's biggest silver mine Chihuahua is situated in the plateau.

Patagonian Plateau

- It is a Piedmont plateau (Arid Landforms) lying in southern part of Argentina.
- It is a rain shadow desert plateau.
- It is an important region for sheep rearing.

Altiplano Plateau or Bolivian Plateau

- It is an intermontane plateau which is located between two ranges of Andes Mountain.
- It is a major area of Tin reserves.

Massif Central

- This plateau lies in the central France.
- It is famous for Grapes cultivation.

Anatolian Plateau

- Also known as Asia Minor, most of Turkey lies on this plateau.
- It is an intermontane plateau lying between Pontiac and Taurus Mountain ranges.
- Tigris – Euphrates Rivers flow through this plateau.
- Precious wool producing Angora goats are found here.

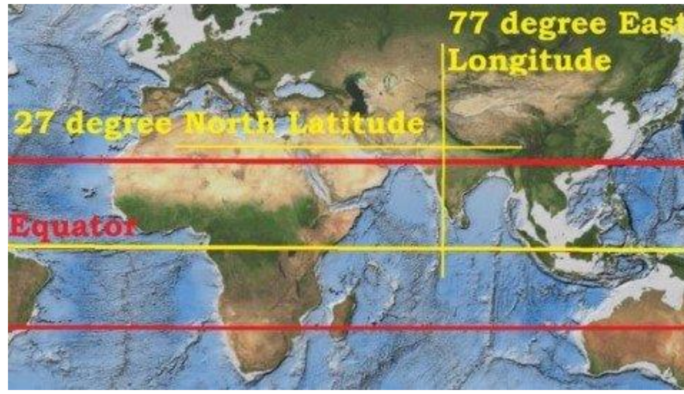
Others

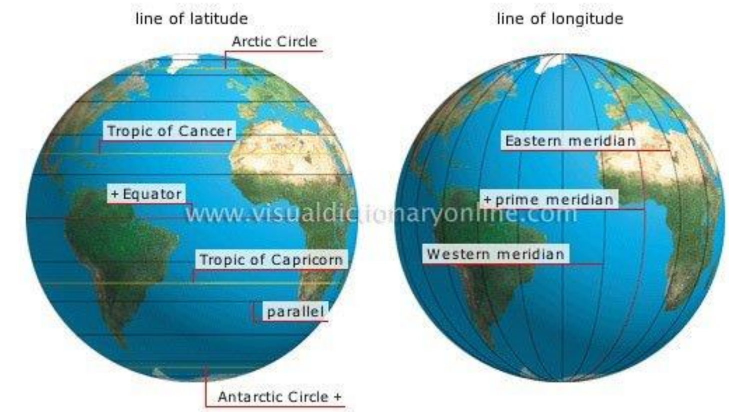
- **Spanish Plateau or Iberian Plateau:** It is situated in the middle of Spain. It is a lava plateau. It is rich in minerals like Iron.
- **Loess Plateau**: It is in China. The soil here is made of fine particles brought by the wind. This fine loamy soil is extremely productive. Crops grown in this soil along the **Yellow River** give great yields.
- **Potwar Plateau:** It is situated in northern plateau (Punjab) region of Pakistan. Its average **'Salt Range'** is located to the south-west of the plateau.
- **Bavarian Plateau:** Southern part of Germany.
- **Ahaggar Plateau:** A small plateau located in Algeria, Sahara.

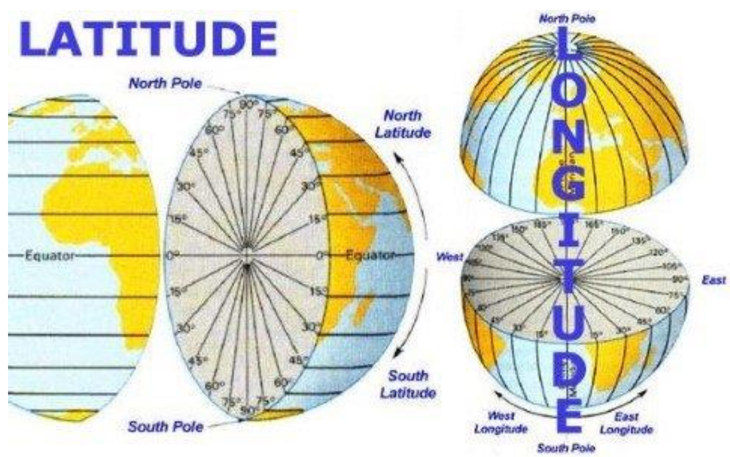
Climatology

Latitudes and Longitudes

- Latitudes and Longitudes are imaginary lines used to determine the location of a place on earth.
- The shape of the earth is **'Geoid'.** And the location of a place on the earth can be mentioned in terms of latitudes and longitudes.
- Example: The location of New Delhi is 28° N, 77° E.







Latitude

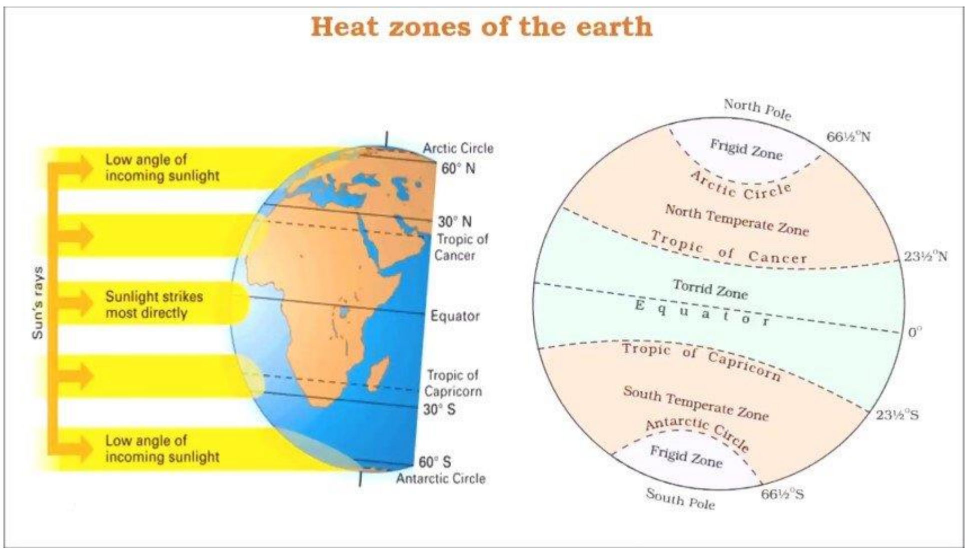
- Latitude is the angular distance of a point on the earth's surface, measured in degrees from the center of the earth.
- ***As the earth is slightly flattened at the poles, the linear distance of a degree of latitude at the pole is a little longer than that at the equator.***
- For example at the equator (0°) it is 68.704 miles, at 45° it is 69.054 miles and at the poles it is 69.407 miles. The average is taken as **69 miles (111km).**

- **1 mile = 1.607 km.**

Important parallels of latitudes

- Besides the equator (0°), the north pole (90°N) and the south pole (90° S), there are four important parallels of latitudes–

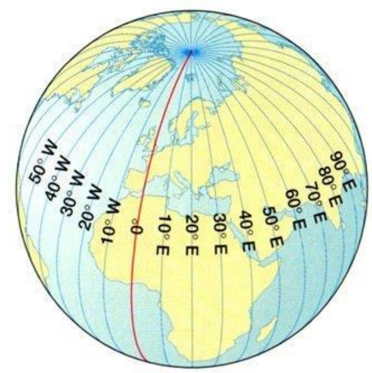
1) **Tropic of Cancer (23½° N) in the northern hemisphere.**
2) **Tropic of Capricorn (23½° S) in the southern hemisphere.**
3) **Arctic circle at 66½° north of the equator.**
4) **Antarctic circle at 66½° south of the equator.**



Latitudinal Heat zones of the earth

- 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. This area, therefore, receives the maximum heat and is called the **torrid zone.**
- 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. As such, the areas bounded by the Tropic of Cancer and the Arctic circle in the northern hemisphere, and the Tropic of Capricorn and the Antarctic circle in the southern hemisphere, have moderate temperatures. These are, therefore, called **temperate 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 raise much above the horizon. Therefore, its rays are always slanting. These are, therefore, called **frigid zones.**

Longitude



Longitude is an angular distance, measured in degrees along the equator east or west of the **Prime (or First) Meridian.**

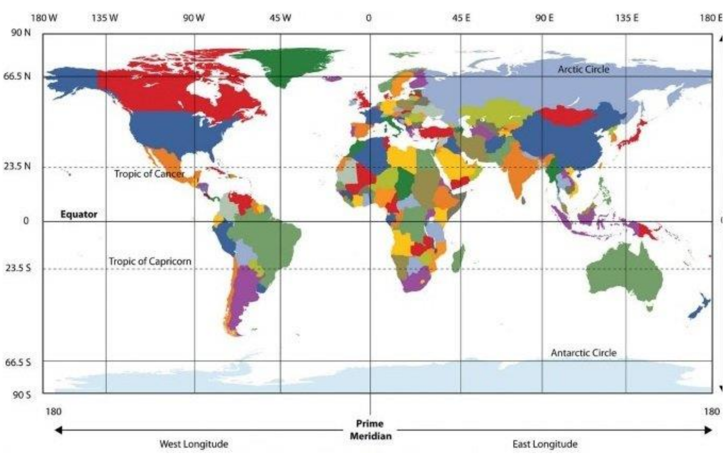
On the globe longitude is shown as a series of semi-circles that run from pole to pole passing through the equator. Such lines are also called **meridians.**

- Unlike the equator which is centrally placed between the poles, any meridian could have been taken to begin the numbering of longitude. It was finally decided in 1884, by international agreement, to choose as the zero meridian the one which passes through the **Royal Astronomical Observatory at Greenwich, near London**.
- This is the **Prime Meridian (0°)** from which all other meridians radiate eastwards and westwards up to 180°.
- As the parallels of latitude become shorter poleward, so the meridians of longitude, which converge at the poles, enclose a narrower space.
- They have one very important function, they **determine local time in relation to**

G.M.T. or **Greenwich Mean Time**, which is sometimes referred to as **World Time.**

Longitude and Time

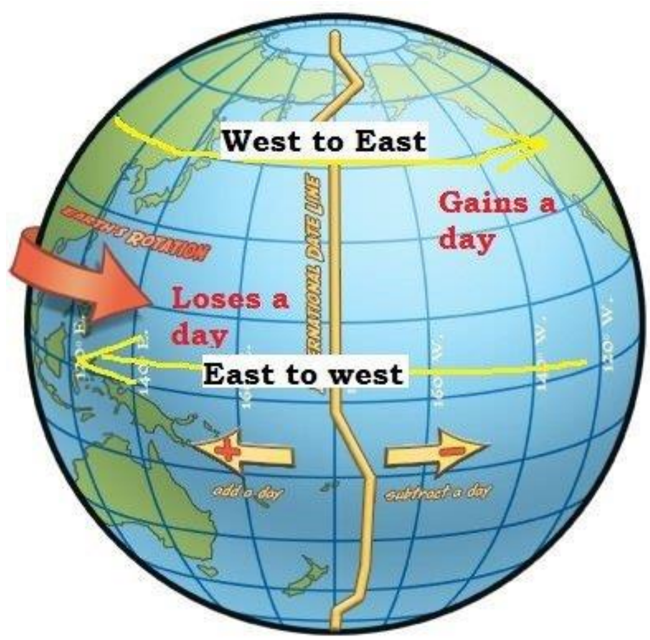
- Since the earth makes one complete revolution of 360° in one day or 24 hours, it passes through **15° in one hour** or **1° in 4 minutes.**
- The earth rotates from west to east, so every 15° we go eastwards, local time is advanced by 1 hour. Conversely, if we go westwards, local time is retarded by 1 hour.
- We may thus conclude that ***places east of Greenwich see the sun earlier and gain time, whereas places west of Greenwich see the sun later and lose time***.
- If we know G.M.T., to find local time, we merely have to add or subtract the difference in the number of hours from the given longitude.



Standard Time and Time Zones

- If each town were to keep the time of its own meridian, there would be much difference in local time between one town and the other.
- Travelers going from one end of the country to the other would have to keep changing their watches if they wanted to keep their appointments. This is impractical and very inconvenient.
- To avoid all these difficulties, a system of standard time is observed by all countries.
- Most countries adopt their standard time from the central meridian of their countries.
- In larger countries such as **Canada, U.S.A., China, and U.S.S.R**, it would be inconvenient to have single time zone. So these countries have multiple time zones.
- Both **Canada and U.S.A.** have **five time zones**—the Atlantic, Eastern, Central, Mountain and Pacific Time Zones. The difference between the local time of the Atlantic and Pacific coasts is nearly five hours.
- U.S.S.R had eleven time zones before its disintegration. **Russia** now has **nine time zones.**

The International Date Line

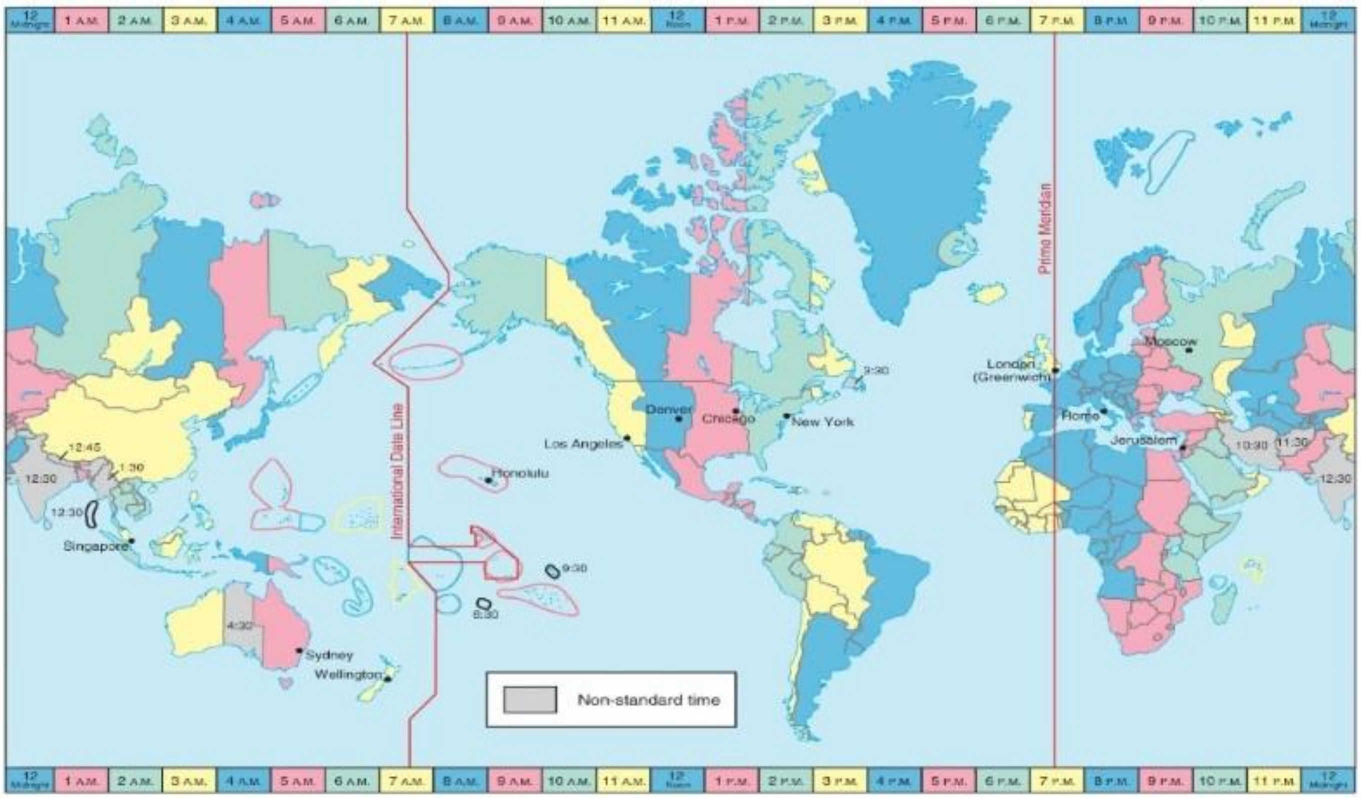


- A traveler going eastwards gains time from Greenwich until he reaches the meridian

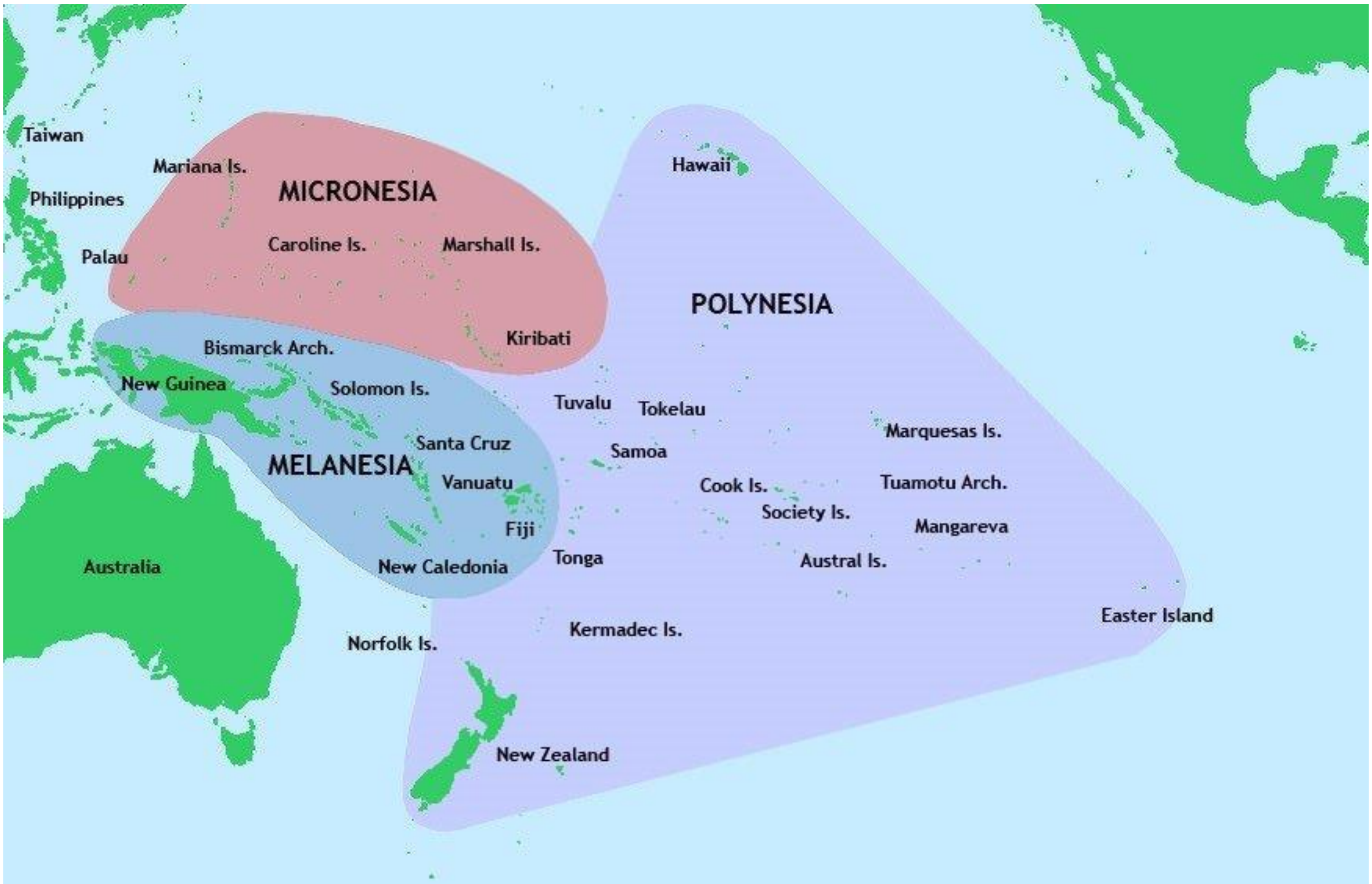
180°E, when he will be 12 hours ahead of G.M.T.

- 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° meridian 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.

Why is the international dateline drawn in a zigzag manner?

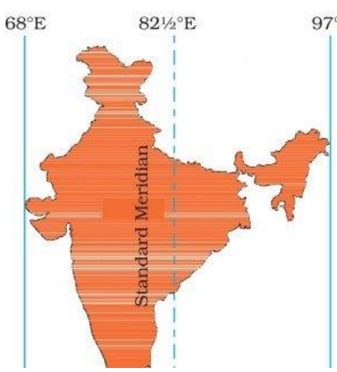


- The International Date Line (IDL) passes through the Pacific Ocean. It is an imaginary line, like longitudes and latitudes.
- The time difference on either side of this line is 24 hours. So, the date changes as soon as one crosses this line.
- Some groups of Islands (**Polynesia, Melanesia, Micronesia**) fall on either of the dateline. So if the dateline was straight, then two regions of the same Island Country or Island group would fall under different date zones. Thus to avoid any confusion of date, this line is drawn through where the sea lies and not land. Hence, the IDL is drawn in a zig-zag manner.



Indian Standard Time

- The Indian Government has accepted the meridian of **82*5° east** for the standard time which is **5hrs. 30 mins, ahead of Greenwich Mean Time**.



Chaibagaan Time

- 150 years ago British colonialists introduced “chaibagaan time” or “bagaan time”, a time schedule observed by tea planters, which was one hour ahead of IST.
- This was done to improve productivity by optimizing the usage of daytime.
- After Independence, Assam, along with the rest of India, has been following IST for the past 66 years.
- The administration of the Indian state of Assam now wants to change it’s time zone back to Chaibagaan time to conserve energy and improve productivity.
- Indian government didn’t accept to such a proposal.

Latitude	**Longitude**
• Parallels • Angular distance of a point from the center of the earth • Equator = 0° Latitude • Latitudes are named south and north of equator	• Meridian • Angular distance along the equator • Prime meridian = longitude

• Their length decreases from equator to poles • Equator has the maximum length • Equator, Tropic of Cancer 23.5° N, Tropic of Capricorn 23.5° S, Arctic circle 66.5° N, Antarctic circle 66.5° S, North Pole 90° N and South Pole 90° S are important latitudes • They help in determining the intensity of sunlight received at a point • They divide earth into torrid, temperate and frigid zones	• Longitudes are named east or west of prime meridian • All longitudes are equal in length • Prime meridian 0° and International Date Line 180° E or 180° W are important longitudes • Used to determine time and date at a location
Both are used to determine the location of a point on earth. The location is identified with Co-ordinates	

1. Statements

1) The shape of the Earth is Geoid.
2) The region that lies between Tropic of Cancer and Tropic of Capricorn is called Torrid Zone.
3) The temperature decreases from equator to poles because of the shape of the earth.
4) North Poles is a latitude.

Which of the above statements are true?

a) 1 and 2 only
b) 1, 3 and 4 only
c) 1, 2 and 3 only
d) All

2. Which of the following is false?

a) Longitudes and Latitudes are useful to determine time at a location.
b) Longitudes and Latitudes are useful to determine a location.
c) GMT is a reference time zone. All other time zones make use of GMT to specify time at a location.
d) Places to the east of Greenwich gain time while those to the west lose.

3. Statements

1) A person travelling from Japan to USA across International Date Line will gain a day.
2) A person travelling from Hawaii to New Zealand across International Date Line will lose a day.
3) It is not continent for a country of greater latitudinal extent but smaller longitudinal extent to have multiple time zones.
4) On a 24 hour clock, the time is 00:00 in London. Then the time in Mumbai on a 12 hour clock will be 05:30 AM.

Which of the above statements are false?

a) None
b) 2 and 4 only
c) 1, 2 and 3 only
d) 3 only

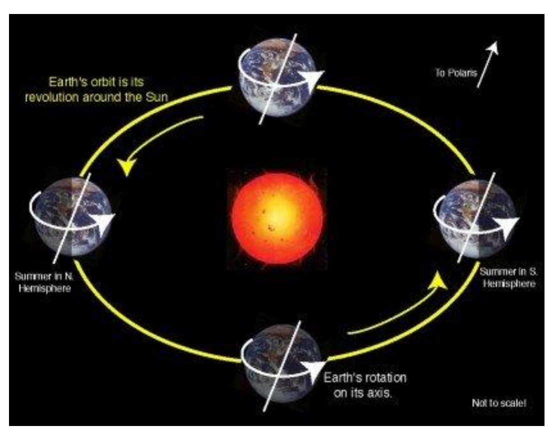
This post: Rotation and Revolution of Earth. This is the 2nd post in Climatology.

Click Here for All posts on Geomorphology.

Previous Post: Longitudes and Latitudes.

Motions of the earth: Rotation and Revolution

- Primarily two motions: **Rotation and Revolution.**



Rotation of Earth

- Earth rotates along its axis from **west to east.**
- It takes approximately 24 hrs to complete on rotation.
- **Days and nights** occur due to rotation of the earth.
- The circle that divides the day from night on the globe is called the **circle of illumination.**
- Earth rotates on a **tilted axis**. Earth's rotational axis makes an angle of **23.5°** with the normal i.e. it makes an angle of **66.5°** with the orbital plane. Orbital plane is the plane of earth's orbit around the Sun.

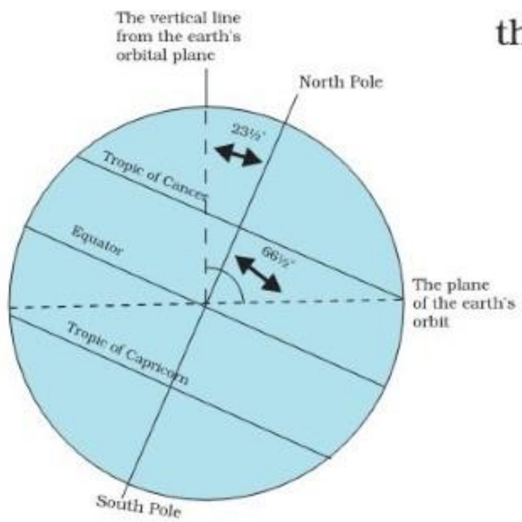


Figure 3.1 : Inclination of the Earth's axis and the orbital plane

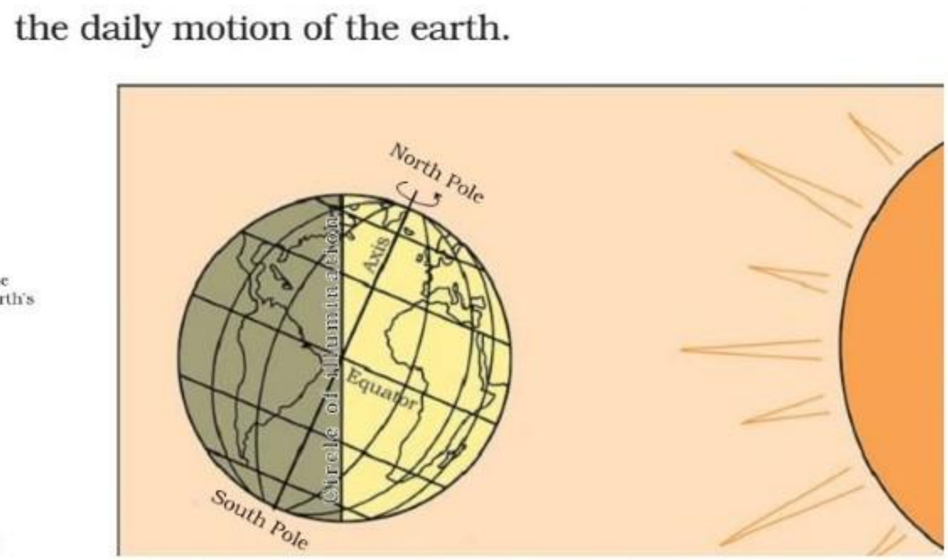
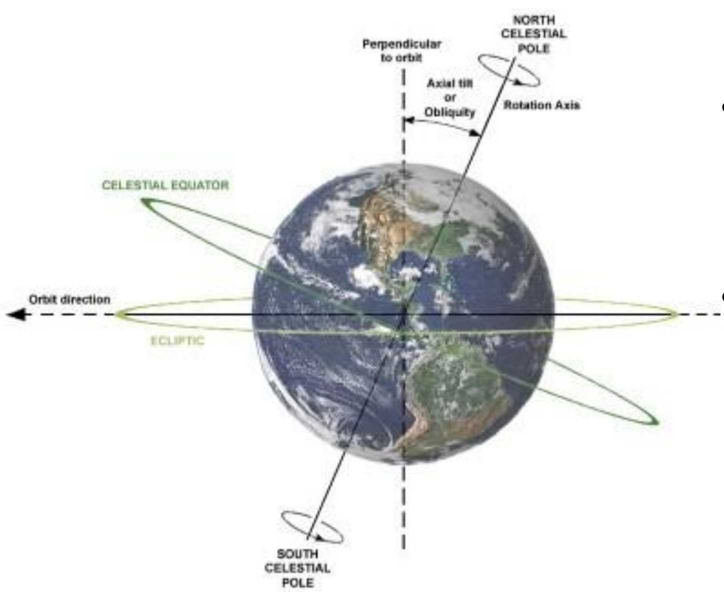
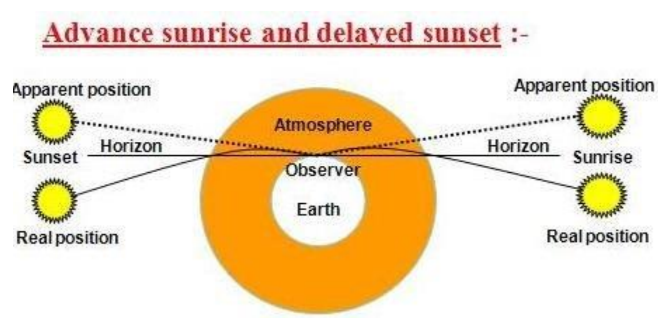


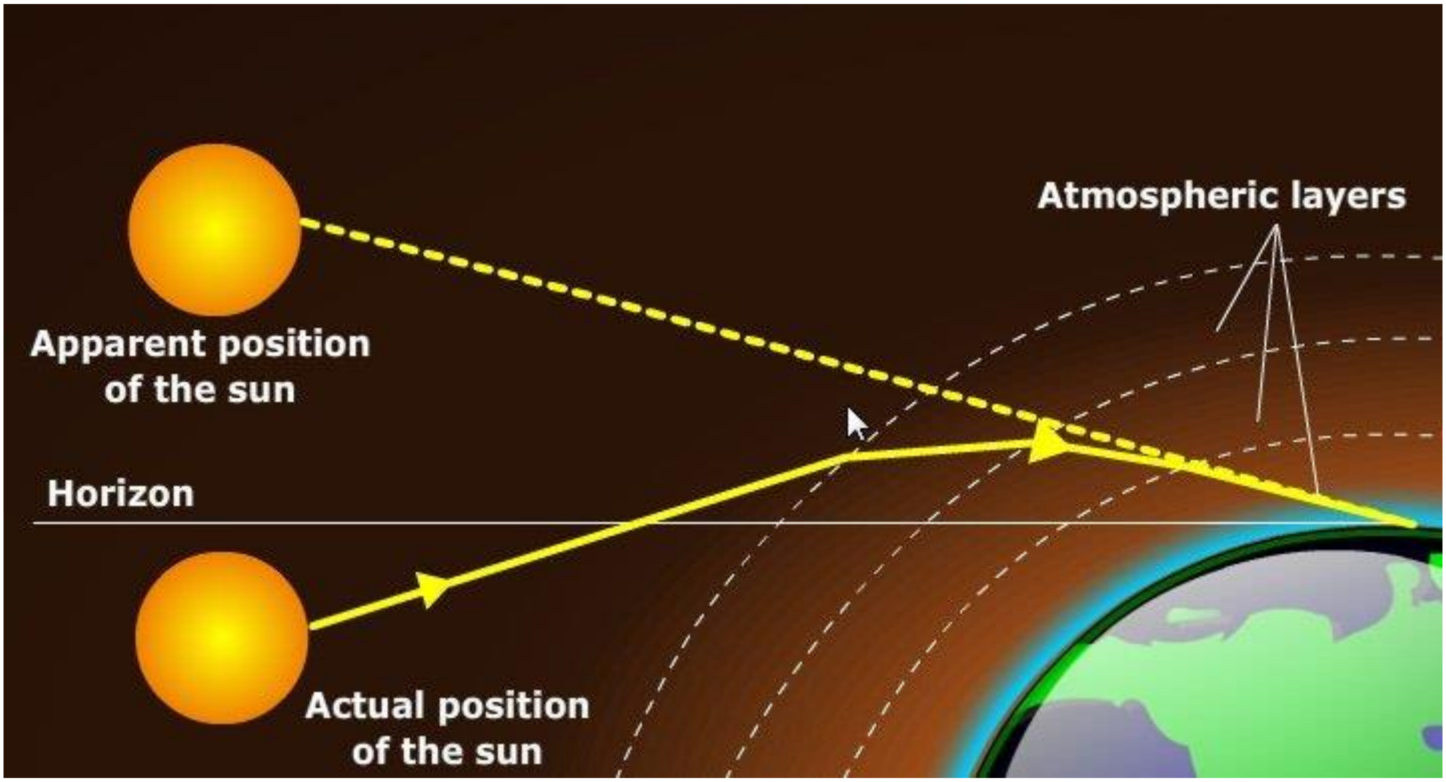
Figure 3.2 : Day and Night on the Earth due to rotation



Why are days always longer than nights at the equator?

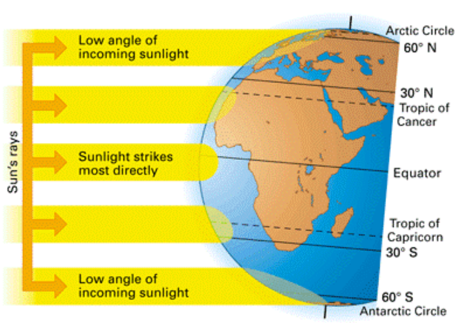
- If there was no atmosphere, there would be no refraction and the daytime and nighttime would be near equal at the equator, at least during equinoxes.
- But due to atmosphere, the sun's rays gets refracted (bending of light). Refraction is particularly stronger during the morning and the evening time when the sun's rays are slant.
- Even though the actual sun is below the horizon, its apparent image would appear above the horizon due to refraction. This makes the days longer than nights at the equator.

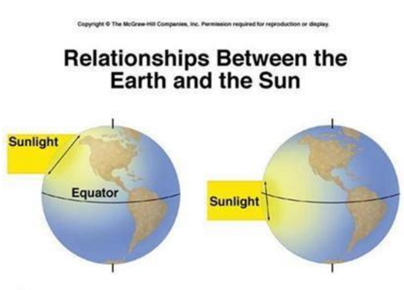




Why temperature falls with increasing latitude (as we move from equator towards poles)?

- Because of the spherical (Geoid) shape of the earth and the position of the sun.
- Because the energy received per unit area decreases from equator to poles.
- Because Equator receives direct sunlight while Poles receive slant or oblique rays of the Sun.





Revolution

- The second motion of the earth around the sun in its orbit is called revolution. It takes **365¼ days** (one year) to revolve around the sun.
- Six hours saved every year are added to make one day (24 hours) over a span of four years. This surplus day is added to the month of February. Thus every fourth year, February is of 29 days instead of 28 days. Such a year with **366 days is called a leap year.**

Solstice

- On **21st June**, the northern hemisphere is tilted towards the sun. The rays of the sun fall directly on the **Tropic of Cancer**. As a result, these areas receive more heat.
- The areas near the poles receive less heat as the rays of the sun are slanting.
- The north pole is inclined towards the sun and the places beyond the **Arctic Circle** experience continuous daylight for about six months.
- Since a large portion of the northern hemisphere is getting light from the sun, it is summer in the regions north of the

equator. The **longest day and the shortest night** at these places occur on **21st June**.

- At this time in the southern hemisphere all these conditions are reversed. It is winter season there. The nights are longer than the days. This position of the earth is called the **summer solstice.**
- On **22nd December**, the Tropic of Capricorn receives direct rays of the sun as the south pole tilts towards it. As the sun's rays fall vertically at the **Tropic of Capricorn** (23½° s), a larger portion of the southern hemisphere gets light. Therefore, it is summer in the southern hemisphere with longer days and shorter nights. The reverse happens in the northern hemisphere. This position of the earth is called the **winter solstice.**

Equinox

- On **21st March** and **September 23rd**, direct rays of the sun fall on the equator. At this position, neither of the poles is tilted towards the sun; so, the whole earth experiences equal days and equal nights. This is called an equinox.
- On 23rd September, it is **autumn season [season after summer and before the beginning of winter]** in the northern hemisphere and **spring season [season after winter and before the beginning of summer]** in the southern hemisphere. The opposite is the case on 21st March, when it is spring in the northern hemisphere and autumn in the southern hemisphere.
- Thus, you find that there are **days and nights and changes in the seasons because of the rotation and revolution of the earth respectively**.
- ***Rotation* === *Days and Nights.***
- ***Revolution* === *Seasons.***

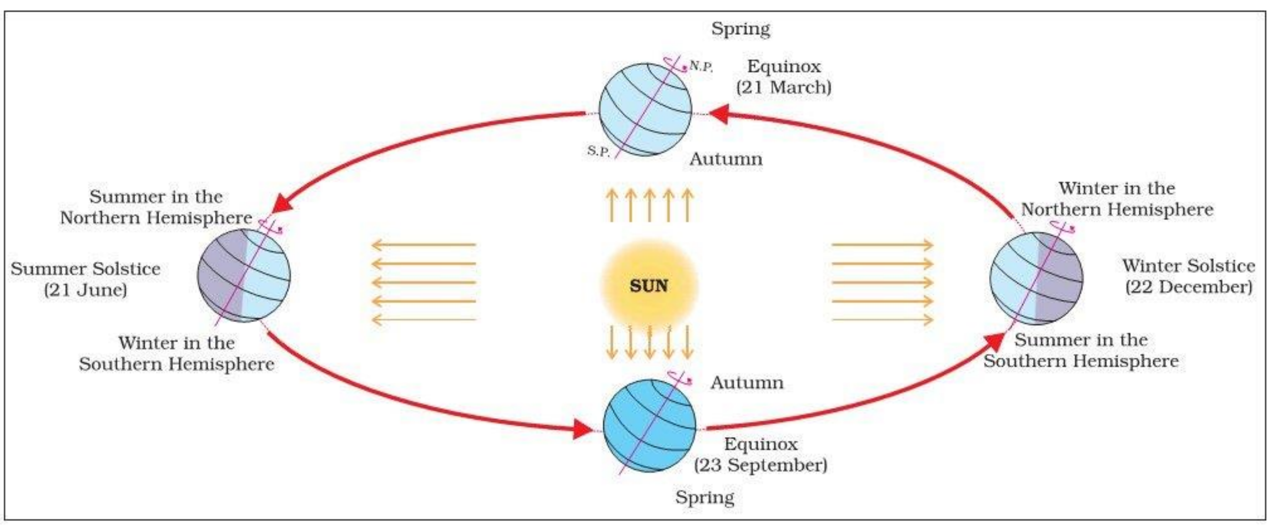
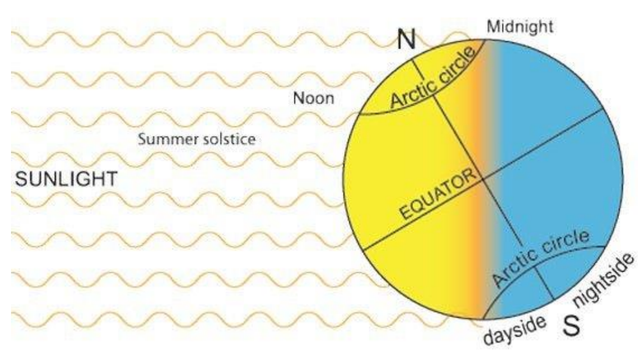


Figure 3.3 : Revolution of the Earth and Seasons

Why regions beyond the Arctic circle receive sunlight all day long in summer?

- This is because of the tilt of the earth.
- Earth's axis at the north pole is tilted towards the sun in summer.
- So the whole of Arctic region falls within the 'zone of illumination' all day long in summer.



Daylight saving in some temperate regions

- Daylight saving time (DST) or **summer time** is the practice of **advancing clocks** during summer months by one hour.
- In DST, evening time is increased by sacrificing the morning hours.

  [Normal days = Start office at 10 AM and close at 5 PM

  In DST = Advance clock by one hour (can be more) = Start office at 9 AM and Close at 4 PM]

- Typically, users in regions with summer time (Some countries in extreme north and south) adjust clocks forward one hour close to the start of spring and adjust them backward in the autumn to standard time.
- Advantage: Putting clocks forward benefits retailing, sports, and other activities that exploit sunlight after working hours. Reduces evening use of incandescent lighting, which was formerly a primary use of electricity.
- Problems: DST clock shifts sometimes complicate timekeeping and can disrupt travel, billing, record keeping, medical devices, heavy equipment, and sleep patterns.

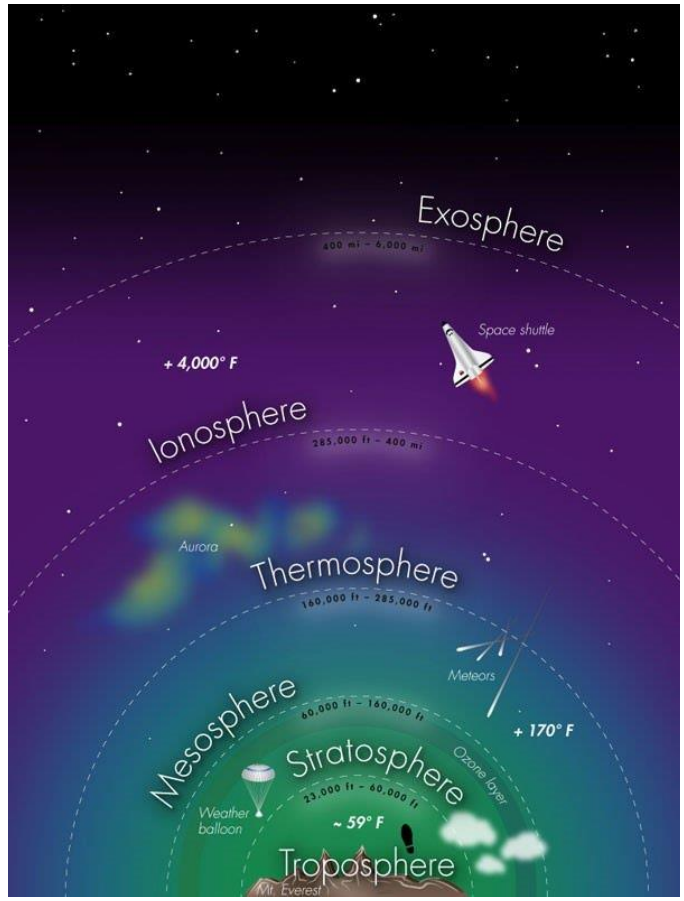
1. Variations in the length of daytime and night time from season to season are due to

a) the earth's rotation on its axis
b) the earth's revolution round the sun in an elliptical manner
c) latitudinal position of the place
d) **revolution of the earth on a tilted axis**

Hint: Revolution + Rotation on a Tilted Axis = = Variation in seasons = = Variation in Day time and Night time

This is 3rd post in Climatology. In this post: Atmosphere – Structure: Troposphere, Stratosphere, Mesosphere, Thermosphere and Exosphere; Composition: Major gasses and other constituents of atmosphere.

Atmosphere



- Our planet earth is enveloped by a deep blanket of gases extending several thousands of kilometres above its surface. This gaseous cover of the earth is known as the atmosphere.
- Like land (lithosphere) and water (hydrosphere), the atmosphere is an integral part of the earth.
- Compared to the earth's radius, the atmosphere appears to be only a very thin layer of gases. However, because of the force of gravity, it is inseparable from the earth.
- **Atmospheric pressure:** The air exerts pressure on earth's surface by virtue of its weight. This pressure is called atmospheric pressure. Atmospheric pressure is the most important climatic element. The atmospheric pressure at sea level is **1034 gm per square centimeter.**

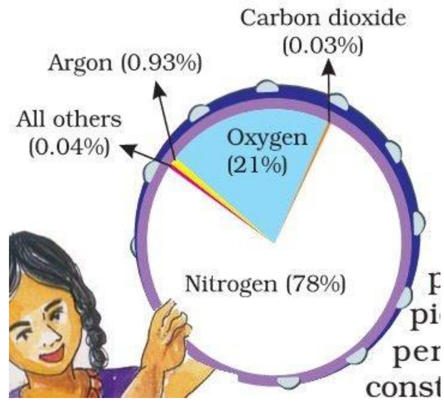
Role of Earth's Atmosphere

- The atmosphere contains various gases like oxygen, carbon dioxide, nitrogen etc.
- Plants require carbon dioxide to survive while animals and many other organisms need oxygen for their survival. The atmosphere supplies these life giving gases.
- All life forms need a particular range of temperature and a specific range of frequencies of solar radiation to carry out their biophysical processes. The atmosphere absorbs certain frequencies and lets through some other frequencies of solar radiation. In other words, the atmosphere **regulates the entry of solar radiation**.
- The atmosphere also keeps the temperature over the earth's surface within certain limits. In the absence of the atmosphere extremes of temperature would exist between day and night over the earth's surface.
- Harmful ultraviolet radiation would find its way through, if the atmosphere (ozone in stratosphere to be specific) were absent.
- The atmosphere also takes care of extra-terrestrial objects like meteors which get burnt up while passing through the atmosphere (mesosphere to be precise) due to friction.
- Weather is another important phenomenon which dictates the direction of a number of natural and man-made processes like plant growth, agriculture, soil-formation, human settlements, etc. Various climatic factors join together to create weather.

Composition of Atmosphere

Table 8.1 : Permanent Gases of the Atmosphere

Constituent	*Formula*	*Percentage by Volume*
Nitrogen	N_2	78.08
Oxygen	O_2	20.95
Argon	Ar	0.93
Carbon dioxide	CO_2	0.036
Neon	Ne	0.002
Helium	He	0.0005
Krypto	Kr	0.001
Xenon	Xe	0.00009
Hydrogen	H_2	0.00005



- The atmosphere is a mixture of many gases. In addition, it contains huge numbers of solid and liquid particles, collectively called **'aerosols'.**
- Some of the gases may be regarded as **permanent atmospheric components** which remain in **fixed proportion** to the total gas volume.
- Other constituents vary in quantity from place to place and from time to time. If the suspended particles, water vapour and other variable gases were excluded from the atmosphere, then the dry air is very stable all over the earth up to an altitude of about 80 kilometres.
- The proportion of gases changes in the higher layers of the atmosphere in such a way that oxygen will be almost in negligible quantity at the height of 120 km. Similarly, carbon dioxide and water vapour are found only up to 90 km from the surface of the earth.
- **Nitrogen and oxygen** make up nearly **99%** of the clean, dry air. The remaining gases are mostly **inert** and constitute about 1% of the atmosphere.
- Besides these gases, large quantities of water vapour and dust particles are also present in the atmosphere. These solid and liquid particles are of great climatic significance.
- Different constituents of the atmosphere, with their individual characteristics, are discussed below.

Oxygen

- Oxygen, although constituting only **21%** of total volume of atmosphere, is the most important component among gases. All living organisms inhale oxygen. Besides, oxygen can combine with other elements to form important compounds, such as, **oxides**. Also, **combustion is not possible without oxygen**.

Nitrogen

- Nitrogen accounts for **78%** of total atmospheric volume. It is a **relatively inert gas**, and is an important constituent of all organic compounds. The main function of nitrogen is to **control combustion by diluting oxygen**. It also indirectly helps in oxidation of different kinds.

Carbon Dioxide

- The third important gas is Carbon Dioxide which constitutes only about **0.03%** of the dry air and is a product of combustion. Green plants, through photosynthesis, absorb carbon dioxide from the atmosphere and use it to manufacture food and keep other bio-physical processes going.
- Being an **efficient absorber of heat**, carbon dioxide is considered to be of great climatic significance. Carbon dioxide is considered to be a very important factor in the **heat energy budget.**
- With increased burning of fossil fuels – oil, coal and natural gas – the carbon dioxide percentage in the atmosphere has been increasing at an alarming rate.
- More carbon dioxide in the atmosphere means more heat absorption. This could significantly raise the temperature at lower levels of the atmosphere thus inducing drastic climatic changes.

Ozone (03)

- Ozone (03) is another important gas in the atmosphere, which is actually a type of oxygen molecule consisting of three, instead of two, atoms. It forms less than **0.00005%** by volume of the atmosphere and is **unevenly distributed**. It is between **20 km and 25** km altitude that the greatest concentrations of ozone are found. It is formed at higher altitudes and transported downwards.
- Ozone plays a **crucial role in blocking the harmful ultraviolet radiation** from the sun.
- Other gases found in almost negligible quantities in the atmosphere are **argon, neon, helium, hydrogen, xenon, krypton, methane etc.**

Water Vapour

- Water Vapour is one of the most variable gaseous substances present in atmosphere – constituting between **0.02% and 4%** of the total volume (in cold dry and humid tropical climates respectively). 90% of moisture content in the atmosphere exists within 6 km of the surface of the earth. Like carbon dioxide, water vapour plays a significant role in the insulating action, of the atmosphere.
- It **absorbs not only the long-wave terrestrial radiation (infrared or heat emitted by earth during nights)**, but also a part of the incoming solar radiation.
- Water vapour is the source of precipitation and clouds. On condensation, it releases **latent heat of condensation** —the **ultimate driving force behind all storms**.

The moisture – carrying capacity of air is directly proportional to the air temperature.

Solid Particles

- The Solid Particles present in the atmosphere consist of sand particles (from weathered rocks and also derived from volcanic ash), pollen grains, small organisms, soot, ocean salts; the upper layers of the atmosphere may even have fragments of meteors which got burnt up in the atmosphere. These solid particles perform the function of absorbing, reflecting and scattering the radiation.
- The solid particles are, consequently, responsible for the **orange and red**

colours at sunset and sunrise and for the **length of dawn (**the first appearance of light in the sky before sunrise**) and twilight (**the soft glowing light from the sky when the sun is below the horizon, caused by the reflection of the sun's rays by the atmosphere. Dusk: the darker stage of twilight.**).** The blue colour of the sky is also due to ***selective scattering*** by dust particles.
- Some of the dust particles are hygroscopic (i.e. readily absorbing moisture from air) in character, and as such, act as **nuclei of condensation.** Thus, dust particles are an important contributory factor in the formation of clouds, fog and hailstones.

Major Greenhouse Gases

Carbon dioxide

- Carbon dioxide is meteorologically a very important gas as it is **transparent to the incoming solar radiation** but **opaque to the outgoing terrestrial radiation**. It absorbs a part of terrestrial radiation and reflects back some part of it towards the earth's surface. It is largely responsible for the greenhouse effect.

Ozone

- Ozone is another important greenhouse gas. But it is very small proportions at the surface.

Water vapour

- Water vapour is also a variable gas in the atmosphere, which decreases with altitude. Water vapour also decreases from the equator towards the poles.
- In the warm and wet tropics, it may account for four per cent of the air by volume, while in the dry and cold areas of desert and polar regions, it may be less than one per cent of the air.
- It also absorbs parts of the insolation from the sun and preserves the earth's radiated heat.
- It thus, acts like a blanket allowing the earth neither to become too cold nor too hot. Water vapour also contributes to the stability and instability in the air.

Methane

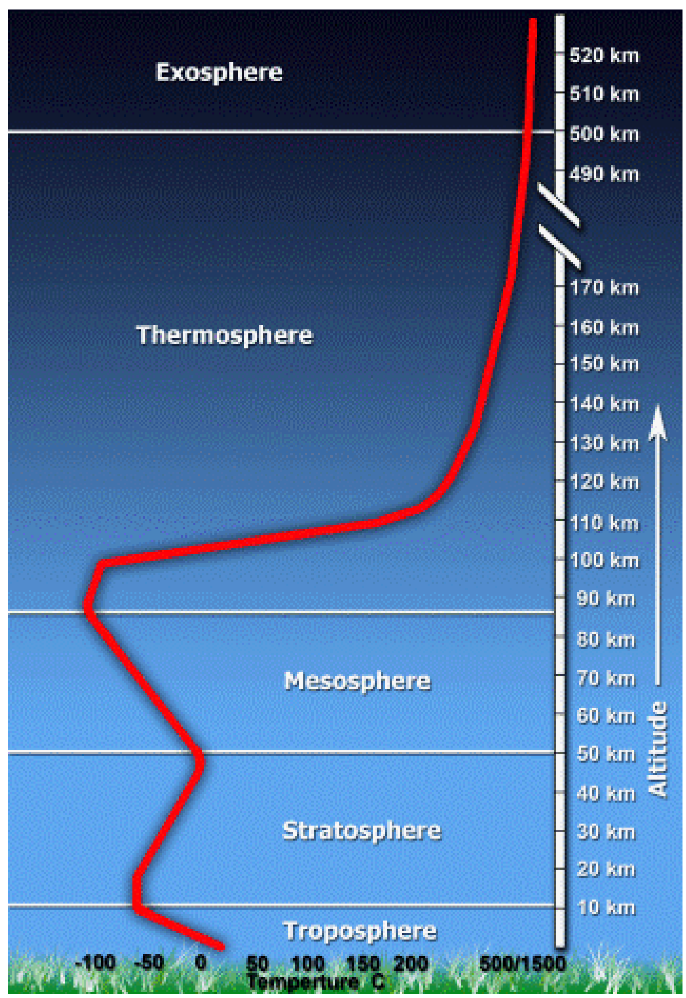
- One of the most important greenhouse gases. It is produced from **decomposition of animal wastes and biological matter**.

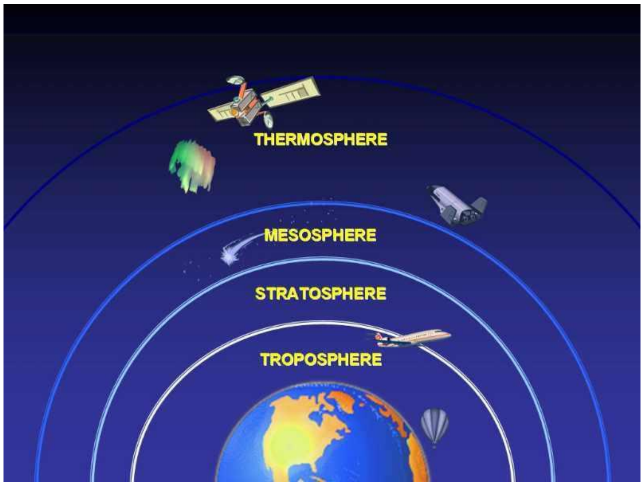
Structure of Atmosphere

- The atmosphere can be studied as a layered entity – each layer having its own peculiar characteristics. These layers are systematically discussed below.

Troposphere

- It is the atmospheric layer between the earth's surface and an altitude of **8 km at the poles and 18 km at the equator.**
- The thickness is greater at the equator, because the **heated air rises to greater heights**.
- The troposphere ends with the **Tropopause**.





- The temperature in this layer, as one goes upwards, falls at the rate of **6.5°C per kilometer**, and reaches -45°C at the poles and -80°C over the equator at Tropopause (greater fall in temperature above equator is because of the greater thickness of troposphere – 18 km).
- The fall in temperature is called **'lapse rate'.** (more about this in future posts)
- The troposphere is marked by **temperature inversion**, turbulence and eddies.
- It is also meteorologically the most significant zone in the entire atmosphere (Almost all the weather phenomena like rainfall, fog and hailstorm etc. are confined to this layer).
- It is also called the **convective region**, since **all convection stops at Tropopause**.
- The troposphere is the theatre for weather because all cyclones, anticyclones, storms and precipitation occur here, as all water vapours and solid particles lie within this.
- The troposphere is influenced by seasons and jet streams.

Tropopause

- Top most layer of troposphere.
- It acts as a boundary between troposphere and stratosphere.
- This layer is marked by **constant temperatures**.

Stratosphere

- It lies beyond troposphere, up to an altitude of 50 km from the earth's surface.
- The temperature in this layer remains constant for some distance but then rises to reach a level of 0°C at 50 km altitude.
- This rise is due to the **presence of ozone** (harmful ultraviolet radiation is absorbed by ozone).
- This layer is **almost free from clouds** and associated weather phenomenon, making conditions **most ideal for flying aeroplanes**. So aeroplanes fly in lower stratosphere, sometimes in upper troposphere where weather is calm.
- Sometimes, **cirrus clouds** are present at lower levels in this layer.

Ozonosphere

- It lies at an altitude between **30 km and 60 km** from the earth's surface and spans the stratosphere and lower mesosphere.
- Because of the presence of ozone molecules, this layer reflects the harmful ultraviolet radiation.
- The ozonosphere is also called **chemosphere** because, a lot of chemical activity goes on here.
- The temperature rises at a rate of **5°C per kilometer** through the ozonosphere.

Mesosphere

- This is an intermediate layer beyond the ozone layer and continues upto an altitude of 80 km from the earth's surface.
- The temperature gradually **falls** to -100°C at 80 km altitude.
- **Meteorites burn up in this layer on entering from the space**.

Thermosphere

- In thermosphere **temperature rises very rapidly** with increasing height.
- **Ionosphere** is a part of this layer. It extends between **80-400 km.**
- This layer helps in ***radio transmission***. In fact, radio waves transmitted from the earth are reflected back to the earth by this layer.

- ***Person would not feel warm because of the thermosphere's extremely low pressure***.
- The **International Space Station and satellites** orbit in this layer**.** (Though temperature is high, the atmosphere is extremely rarified – gas molecules are spaced hundreds of kilometers apart. Hence a person or an object in this layer doesn't feel the heat)
- **Aurora's** are observed in lower parts of this layer.

Ionosphere

- This layer is located between 80 km and 400 km and is an **electrically charged layer**.
- This layer is characterized by **ionization of atoms**.
- Because of the electric charge, radio waves transmitted from the earth are reflected back to the earth by this layer.
- Temperature again starts increasing with height because of radiation from the sun.

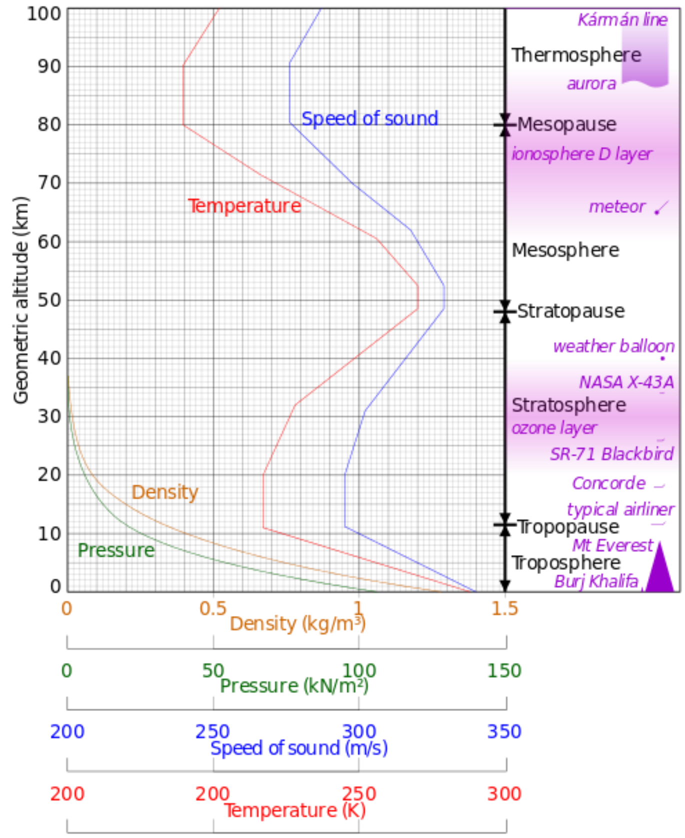
Exosphere

- This is the **uppermost layer** of the atmosphere extending beyond the ionosphere above a height of about 400 km.
- The air is extremely rarefied and the temperature gradually increases through the layer.
- Light gases like **helium and hydrogen** float into the space from here.
- Temperature gradually increases through the layer. (As it is exposed to direct sunlight)
- This layer coincides with space.

Speed of sound follows temperature profile

- This is because speed of sound is directly proportional to temperature as we move away from earth.

In this Post: Temperature Distribution on Earth, Insolation, Factors Affecting



Temperature Distribution, Latitudinal Heat Balance, Heat Budget, Mean Annual Temperature Distribution and Seasonal Temperature Distribution – January and July.

Temperature Distribution on Earth

- Sun is the ultimate source of heat. And the differential heat received from sun by different regions on earth is the ultimate reason behind all climatic features. So understanding the patterns of distribution of temperature in different seasons is important for understanding various climatic features like wind systems, pressure systems, precipitation etc..

Insolation

- Earth intercepts only **one in two billion parts** of solar radiation. This intercepted radiation is called Insolation.
- Insolation == Proportion of Solar energy received or intercepted by earth.
- Some heat within the core and mantle is transferred to the surface and ocean bottoms through volcanoes, springs and

geysers. But this heat received at the surface form interiors of the earth is negligible compared to that received from sun.

- Earth receives Sun's radiation (heat) in the form of **short waves (visible light + wavelengths below visible light – most of it is ultraviolet radiation)** which are of electromagnetic nature. The earth absorbs short wave radiation during daytime and reflects back the heat received into space as **long-wave radiation (mostly infrared radiation)** during night.

Name	Wavelength	Frequency (Hz)	Photon Energy (eV)
Gamma ray	Less than 0.01 nm	more than 10 EHz	100 kev - 300+ GeV
X - ray	0.01 - 10 nm	30 EHz - 30 PHz	120 eV - 120 keV
Ultraviolet	10 nm - 400 nm	30 PHz - 790 THz	3 eV - 124 eV
Visible	390 nm - 750 nm	790 THz - 405 THz	1.7 eV - 3.3 eV
Infrared	750 nm - 1 mm	405 THz - 300 GHz	1.24 meV -1.7 eV
Microwave	1 mm - 1 meter	300 GHz - 300 MHz	1.24 μ eV - 1.24 meV
Radio	1 mm - km	300 GHz - 3 Hz	12.4 feV - 1.24 meV

Ways of Transfer of Heat Energy

- The heat energy from the solar radiation is received by the earth through three mechanisms—
- Radiation == Heat transfer from one body to another **without actual contact or movement**. It is possible in relatively emptier space, for instance, from the sun to the earth through space.
- Conduction == Heat transfer through matter by **molecular activity**. Heat transfer in iron and other metals is by conduction. Generally, denser materials like water are good conductors and a lighter medium like air is a bad conductor of heat.
- Convection == Transfer of heat energy by **actual transfer of matter** or substance from one place to another. (heat transfer by convection cycles in atmosphere as well as oceans)

Factors Affecting Temperature Distribution

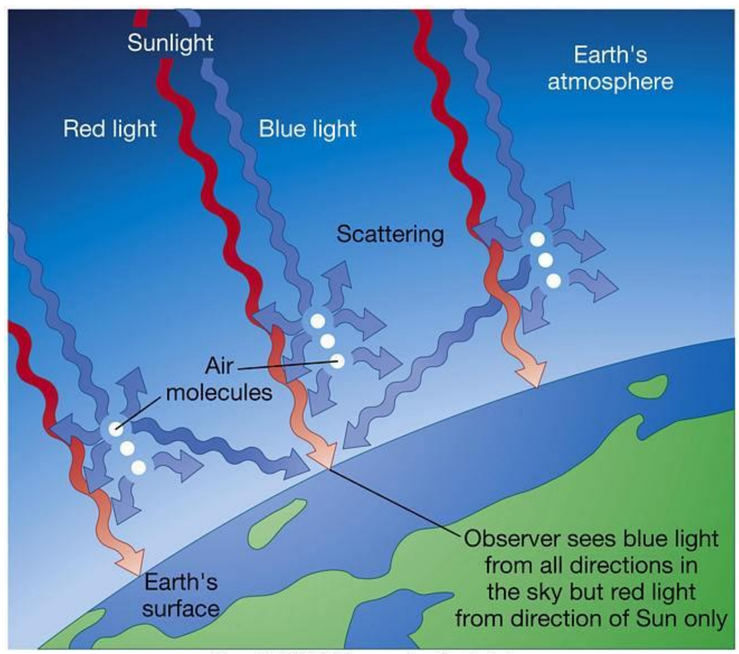
The Angle of Incidence or the Inclination of the Sun's Rays

Duration of Sunshine

- Heat received depends on day or night; clear sky or overcast, summer or winter etc..

Transparency of Atmosphere

- Aerosols (smoke, sooth), dust, water vopour, clouds etc. effect transparency.
- If the wavelength (X) of the radiation is more than the radius of the obstructing particle (such as a gas), then **scattering** of radiation takes place.
- If the wavelength is less than the obstructing particle (such as a dust particle), then total **reflection** takes place.
- **Absorption** of solar radiation takes place if the obstructing particles happen to be water vapour, ozone molecules, carbon dioxide molecules or clouds.
- Most of the light received by earth is **scattered light.**



Land-Sea Differential

- Albedo of land is much greater than albedo of oceans and water bodies. Especially snow covered areas reflect up to 70%-90% of insolation.
- Average penetration of sunlight is more in water – up to 20 metres, than in land – where it is up to 1 metre only. Therefore,

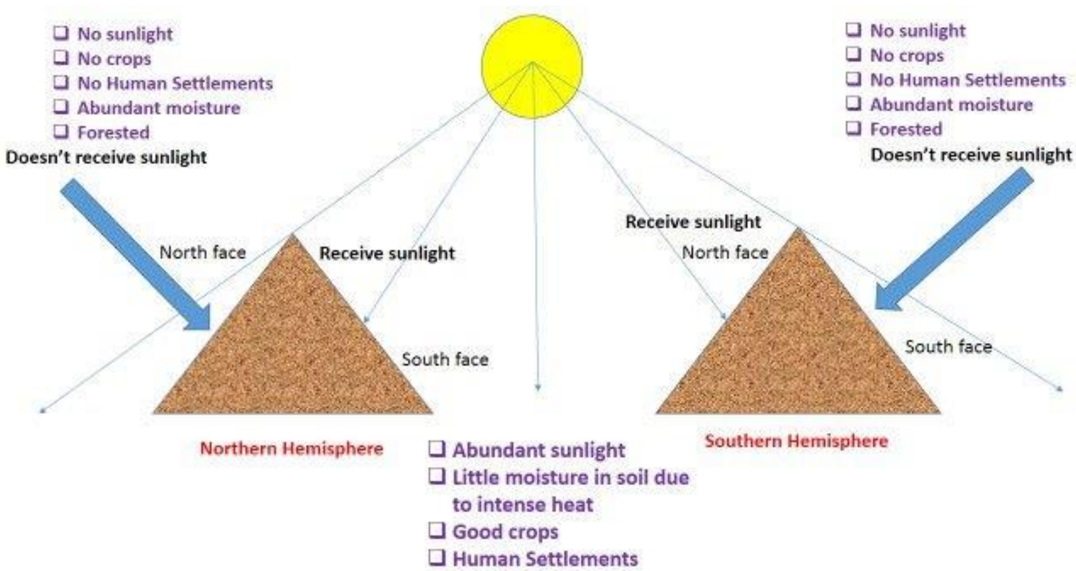
land cools or becomes hot more rapidly compared to oceans. In oceans, continuous convection cycle helps in heat exchange between layers keeping diurnal and annual temperature ranges low. (more while studying salinity and temperature distribution of oceans)

- The specific heat of water is 2.5 times higher than landmass, therefore water takes longer to get heated up and to cool down.

Prevailing Winds

- Winds transfer heat from one latitude to another. They also help in exchange of heat between land and water bodies.
- The oceanic winds have the capacity to take the moderating influence of the sea to coastal areas – reflected in cool summers and mild winters. This effect is pronounced only on the windward side (the side facing the ocean).
- The leeward side or the interiors do not get the moderating effect of the sea, and therefore experience extremes of temperature.

Aspects of Slope



- The direction of the slope and its angle control the amount of solar radiation received locally. Slopes more exposed to the sun receive more solar radiation than those away from the sun's direct rays.
- Slopes that receive direct Sun's rays are dry due to loss of moisture through excess evaporation. These slopes remain barren if irrigational facilities are absent. But slopes with good irrigational facilities are good for agriculture due to abundant sunlight available. They are occupied by dense human settlements.
- Slopes that are devoid of direct sunlight are usually well forested.

Ocean Currents

- Ocean currents influence the temperature of adjacent land areas considerably. (more while studying ocean currents).

Altitude

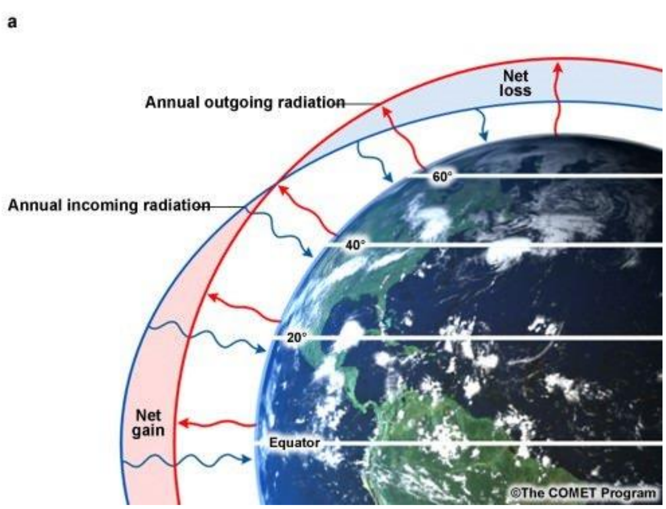
- With increase in height, pressure falls, the effect of greenhouse gases decreases and hence temperature decreases (applicable only to troposphere).
- The normal lapse rate is roughly 1^0 C for every 165 metres of ascent.

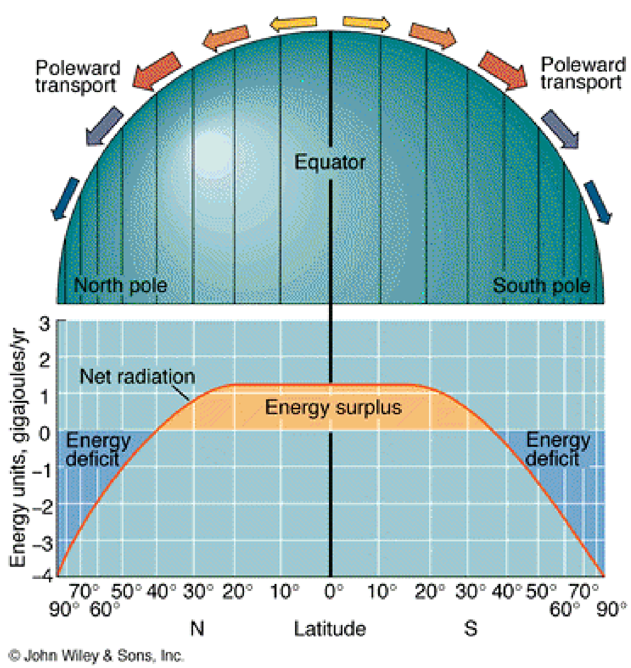
Earth's Distance form Sun

- During its revolution around the sun, the earth is farthest from the sun **(152 million km on 4th July)**. This position of the earth is called **aphelion.**

- On **3rd January**, the earth is the nearest to the sun **(147 million km).** This position is called **perihelion.**
- Therefore, the annual insolation received by the earth on 3rd January is slightly more than the amount received on 4th July.
- However, the effect of this variation in the solar output is masked by other factors like the distribution of land and sea and the atmospheric circulation.
- Hence, this variation in the solar output does not have great effect on daily weather changes on the surface of the earth.

Latitudinal Heat Balance

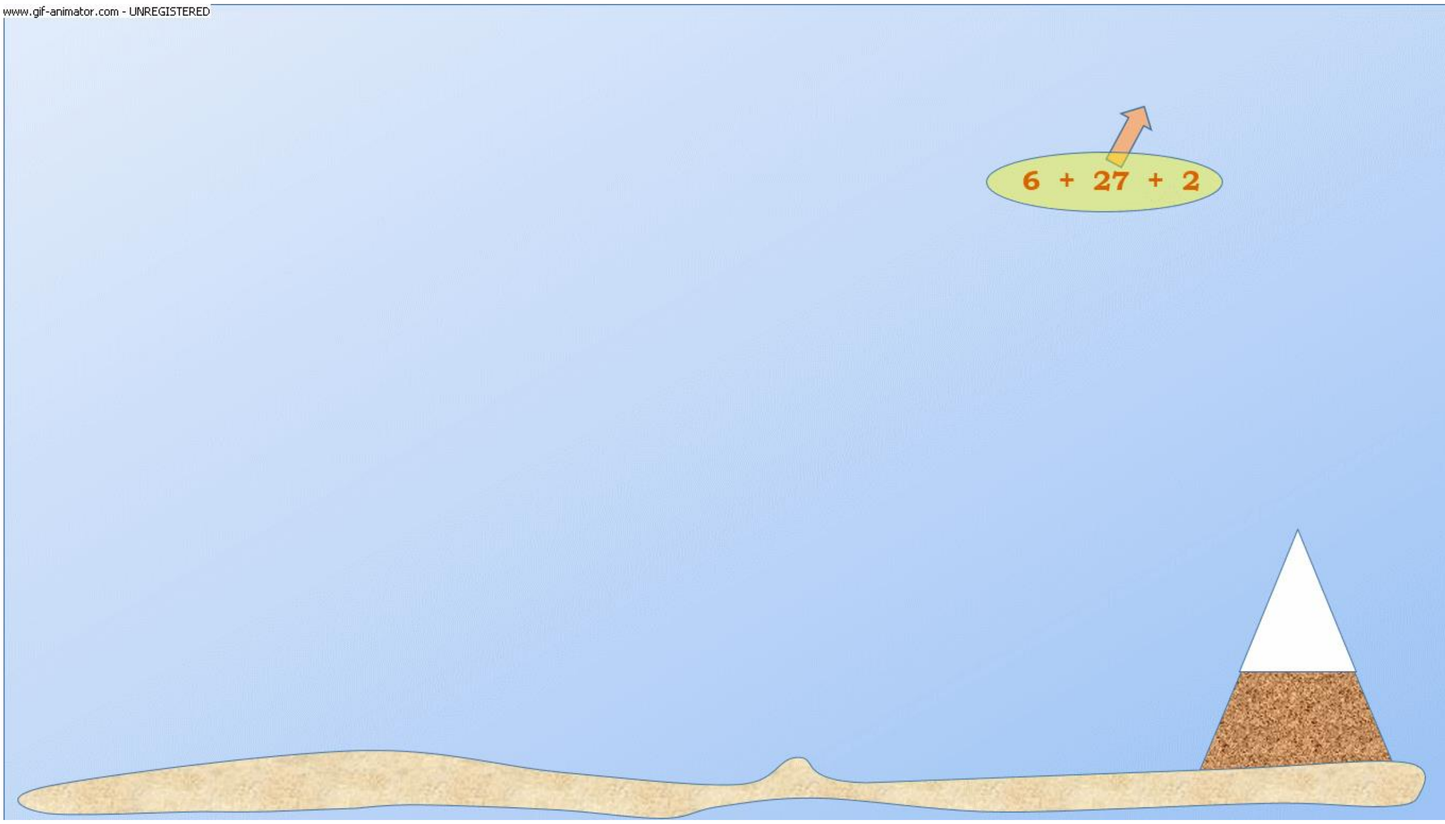




- The amount of insolation received varies from latitude to latitude.
- Regions within the equator and 40° N and S latitudes receive abundant sunlight and hence more heat will be gained than lost. Hence they are **energy surplus regions.**
- Regions beyond 40° N and S latitudes lose more heat than that gained from sunlight. Hence they are **energy deficit regions** (This is because of **slant sunlight and high albedo of polar regions**).
- Going by this logic, the tropics should have been getting progressively hotter and the poles getting progressively cooler. And the planet would have been inhospitable except for few regions near mid-latitudes. But, in reality, this does not happen.
- The atmosphere **(planetary winds)** and the oceans **(ocean currents)** transfer excess heat from the tropics (energy surplus region) towards the poles (energy deficit regions) making up for heat loss at higher latitudes.
- ***And most of the heat transfer takes place across the mid-latitudes (30° to 50°)[more while studding jet streams and cyclones], and hence much of the stormy weather is associated with this region.***
- Thus, the transfer of surplus energy from the lower latitudes to the deficit energy zone of the higher latitudes, maintains an overall balance over the earth's surface.

Heat Budget

- The earth receives a certain amount of Insolation **(short waves)** and gives back heat into space by terrestrial radiation **(longwave radiation).** Through this give and take, or the heat budget, the earth maintains a constant temperature.



Gif Image: Watch in power point in full screen mode

The Mean Annual Temperature Distribution

- **Isotherm** == An imaginary line joining places having equal temperatures.
- The horizontal or latitudinal distribution of temperature is shown with the help of a map with isotherms.
- Effects of altitude is not considered while drawing an isotherm. All the temperatures are reduced to sea levels.

General characteristics of isotherms.

- **Generally follow the parallels**: Isotherms have close correspondence with the latitude parallels mainly because the same amount of insolation is received by all the points located on the same latitude.
- **Sudden bends at ocean – continent boundaries:** Due to differential heating of land and water, temperatures above the oceans and landmasses vary even on the same latitude. (we have seen how land sea differential effects temperature distribution)
- **Narrow spacing** between isotherms indicate **rapid change** in temperature (high thermal gradient).
- **Wide spacing** between isotherms indicate **small or slow change** in temperatures (low thermal gradient).

General Temperature Distribution

- The highest temperatures occur over tropics and sub-tropics (high insolation). The lowest temperatures occur in polar and sub polar regions. in continents due to the effect of continentiality.
- Diurnal and annual range of temperatures are highest in the interiors of continents due to the effect of **continentiality** (in continental interiors these will no moderating effect of oceans).
- Diurnal and annual range of temperatures are least in oceans. [high specific heat of water and mixing of water keep the range low]
- Low temperature gradients are observed over tropics (sun is almost overhead the entire year) and high temperature gradients over middle and higher latitudes

(sun's apparent path varies significantly from season to season).

- Temperature gradients are usually low over the eastern margins of continents. (This is because of **warm ocean currents**)
- Temperature gradients are usually high over the western margins of continents. (This is because of **cold ocean currents**)
- The isotherms are irregular over the northern hemisphere due to an **enhanced land-sea contrast.** Because of predominance of land over water in the north, the **northern hemisphere is warmer**. The thermal equator (ITCZ) lies generally to the north of geographical equator.
- While passing through an area with warm ocean currents, the isotherms show a poleward shift. (North Atlantic Drift and Gulf Stream combined with westerlies in Northern Atlantic; Kurishino Current and North Pacific current combined with westerlies in Northern Pacific) (we will see about ocean currents in detail later.)
- Mountains also affect the horizontal distribution of temperature. For instance, the Rockies and the Andes stop the oceanic influence from going inwards into North and South America.

Seasonal Temperature Distribution

- The global distribution of temperature can well be understood by studying the temperature distribution in January and July.
- The temperature distribution is generally shown on the map with the help of isotherms. The Isotherms are lines joining places having equal temperature.
- In general the effect of the latitude on temperature is well pronounced on the map, as the isotherms are generally parallel to the latitude. The deviation from this general trend is more pronounced in January than in July, especially in the northern hemisphere.
- In the northern hemisphere the land surface area is much larger than in the southern hemisphere. Hence, the effects of land mass and the ocean currents are well pronounced.

Seasonal Temperature Distribution – January

During January, it is winter in the northern hemisphere and summer in the southern hemisphere.

- **The western margins of continents are warmer than their eastern counterparts, since the Westerlies are able to carry high temperature into the landmasses.**
- The temperature gradient is close to the eastern margins of continents. The isotherms exhibit a more regular behavior in the southern hemisphere.

Northern Hemisphere

- The isotherms deviate to the north over the ocean and to the south over the continent. This can be seen on the North Atlantic Ocean.
- The presence of warm ocean currents, Gulf Stream and North Atlantic drift, make the Northern Atlantic Ocean warmer and the isotherms show a poleward shift indicating that the oceans are warmer and are able to carry high temperatures poleward.
- An equator ward bend of the isotherms over the northern continents shows that the landmasses are overcooled and that polar cold winds are able to penetrate southwards, even in the interiors. It is much pronounced in the Siberian plain.
- Lowest temperatures are recorded over northern Siberia and Greenland.

Southern Hemisphere

- The effect of the ocean is well pronounced in the southern hemisphere. Here the isotherms are more or less parallel to the latitudes and the variation in temperature is more gradual than in the northern hemisphere.

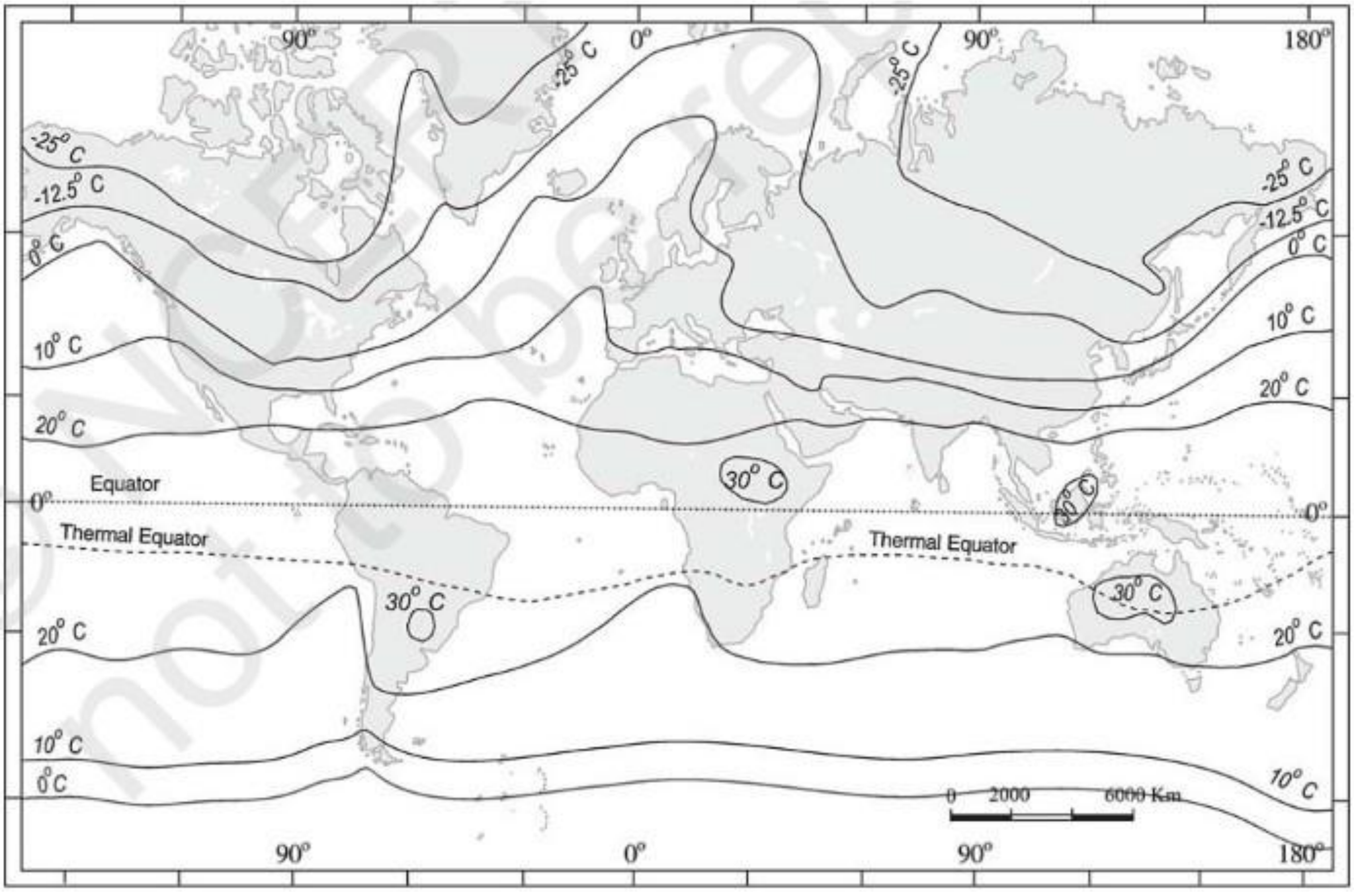


Figure 9.4 (a) : The distribution of surface air temperature in the month of January

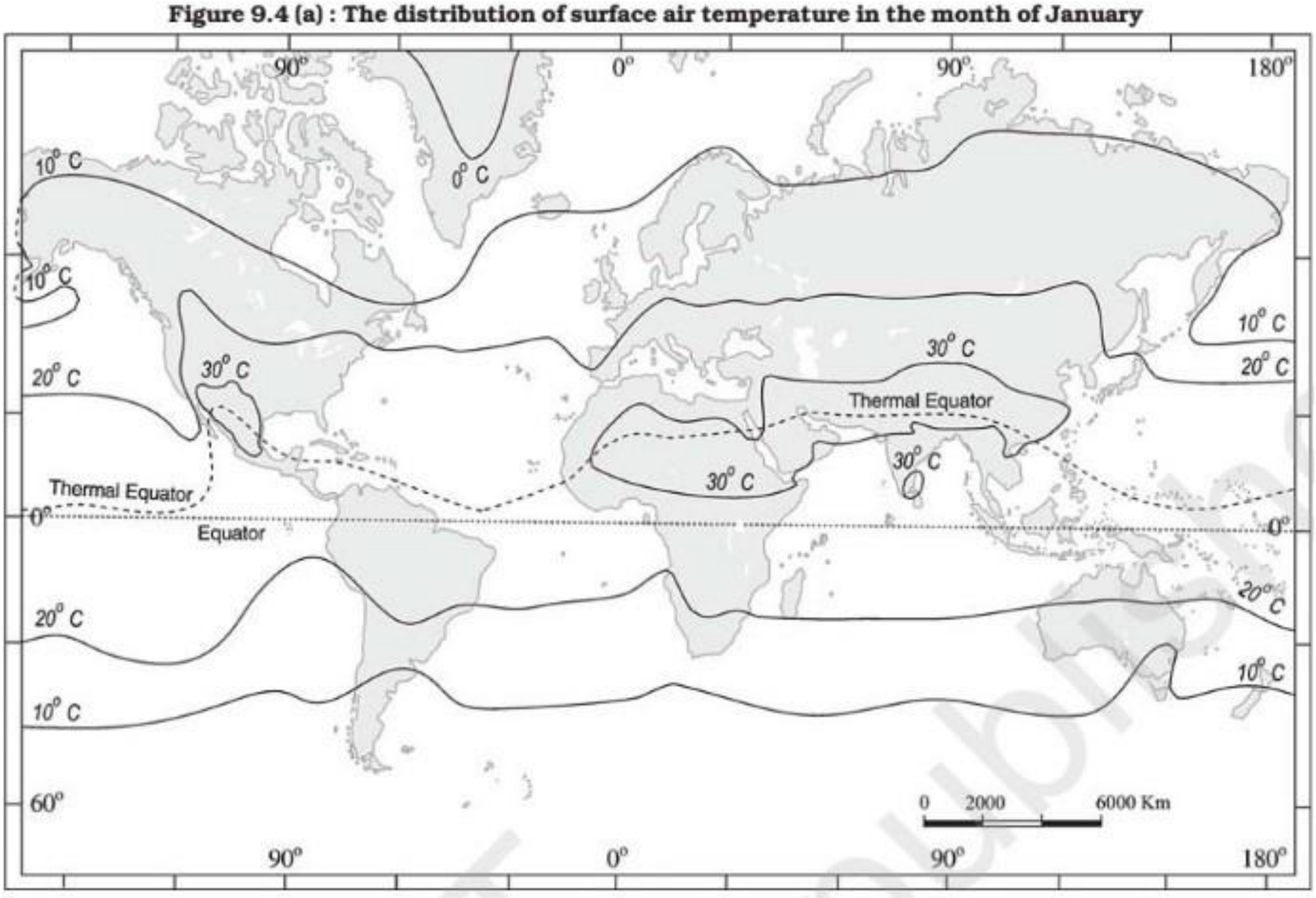


Figure 9.4 (b) : The distribution of surface air temperature in the month of July

- The high temperature belt runs in the southern hemisphere, somewhere along 30°S latitude.
- The thermal equator lies to the south of geographical equator (because the Intertropical Convergence Zone or ITCZ has shifted southwards with the apparent southward movement of the sun).

Seasonal Temperature Distribution – July

- During July, it is summer in the northern hemisphere and winter in the southern hemisphere. The isothermal behavior is the opposite of what it is in January.
- In July the isotherms generally run parallel to the latitudes. The equatorial oceans record warmer temperature, more than 27°C. Over the land more than 30°C is noticed in the subtropical continental region of Asia, along the 30° N latitude.

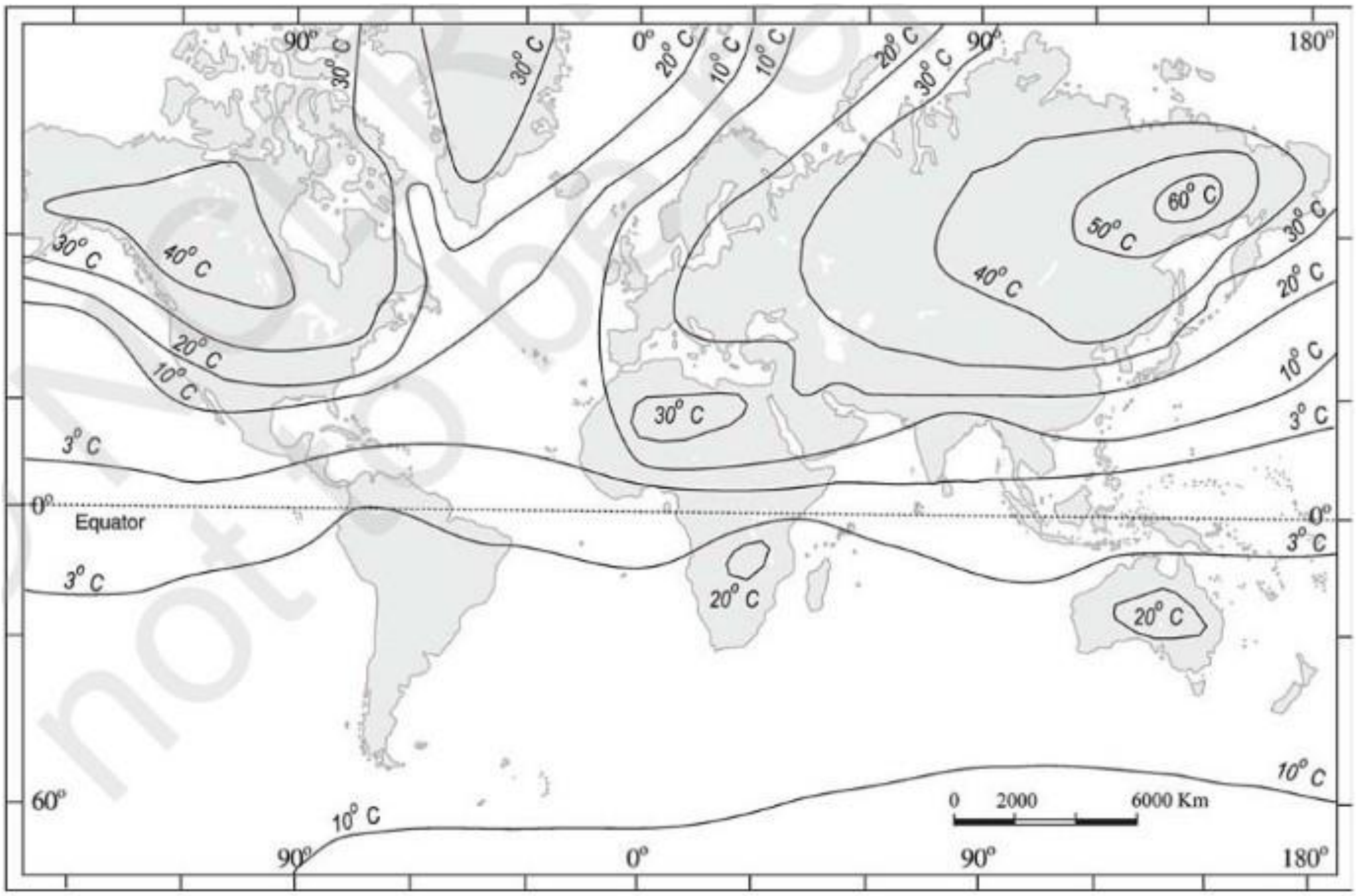


Figure 9.5 : The range of temperature between January and July

Northern Hemisphere

- The highest range of temperature is more than 60° C over the north-eastern part of Eurasian continent. This is due to continentiality. The least range of temperature, 3°C, is found between 20° S and 15° N.
- Over the northern continents, a poleward bend of the isotherms indicates that the landmasses are overheated and the hot tropical winds are able to go far into the northern interiors.
- The isotherms over the northern oceans show an equator ward shift indicating that the oceans are cooler and are able to carry the moderating effect into tropical interiors. The lowest temperatures are experienced over Greenland.
- The highest temperature belt runs through northern Africa, west Asia, north-west India arid southeastern USA. The temperature gradient is irregular and follows a zig-zag path over the northern hemisphere.

Southern Hemisphere

- The gradient becomes regular over the southern hemisphere but shows a slight bend towards the equator at the edges of continents. Thermal equator now lies to the north of the geographical equator.

Questions from NCERT

1. The atmosphere is mainly heated by the:

(a) Short wave solar radiation
(b) Long wave terrestrial radiation
(c) Reflected solar radiation
(d) Scattered solar radiation

2. The main reason that the earth experiences highest temperatures in the subtropics in the northern hemisphere rather than at the equator is:

(a) Subtropical areas tend to have less cloud cover than equatorial areas.
(b) Subtropical areas have longer day hours in the summer than the equatorial.
(c) Subtropical areas have an enhanced "greenhouse effect" compared to equatorial areas.
(d) Subtropical areas are nearer to the oceanic areas than the equatorial locations.

Match the following

(i) Insolation	(a) The difference between the mean temperature of the warmest and the coldest months
(ii) Albedo	(b) The lines joining the places of equal temperature
(iii) Isotherm	(c) The incoming solar radiation
(iv) Annual range	(d) The percentage of visible light reflected by an object

30 words

1) How does the unequal distribution of heat over the planet earth in space and time cause variations in weather and climate?
2) What are the factors that control temperature distribution on the surface of the earth?
3) In India, why is the day temperature maximum in May and why not after the summer solstice?
4) Why is the annual range of temperature high in the Siberian plains

150 words

1) How do the latitude and the tilt in the axis of rotation of the earth affect the amount of radiation received at the earth's surface?
2) Discuss the processes through which the earth-atmosphere system maintains heat balance.
3) Compare the global distribution of temperature in January over the northern and the southern hemisphere of the earth.

Condensation of water vapour, thunderstorms, cyclonic and anticyclonic conditions etc. depend on **Adiabatic Lapse Rate**. Adiabatic Lapse Rate determines the **Rate Of Condensation** and the rate of condensation determines the amount of **Latent Heat of Condensation** Released.

All the explanation below is meant to explain 'Adiabatic Lapse Rate' and 'Latent Heat of Condensation'. These two terms occur frequently in almost all the future topics of climatology. They won't be specifically asked in the exam. But understanding them once for all will help immensely in understanding the future posts on climatology.

Lapse Rate

- Lapse rate is rate of change in temperature observed while moving upward through the Earth's atmosphere (troposphere to be specific).
- The lapse rate is considered **positive** when the temperature decreases with elevation, **zero** when the temperature is constant with elevation, and **negative** when the temperature increases with elevation **(temperature inversion)**.
- The lapse rate of **non-rising air** – commonly referred to as the normal, or **Environmental, Lapse Rate (ELR)** – is highly variable, being affected by **radiation, convection,** and

condensation; it averages about **6.5 °C per kilometer** in the lower atmosphere (troposphere).

Why does temperature fall with elevation

- When we move up a hill, we notice a fall in temperature. This fall in temperature with elevation is primarily due to two reasons.

1. With increase in elevation, the **atmospheric pressure falls**. Fall in pressure implies that the temperature also falls [Pressure is directly proportional to Temperature and vice versa]
2. With increase in elevation, the **concentration of greenhouse gases decrease** (Water vapor and carbon dioxide fall sharply with elevation). Hence the heat absorption capacity of atmosphere will also decrease.

This sort of fall in temperature with elevation is called **Temperature Lapse** and the rate at which it happens is called Temperature Lapse Rate or simply Lapse rate.

Adiabatic Lapse rate

- Lapse rate is the rate of fall in temperature of atmosphere with elevation.
- Adiabatic Lapse Rate is the rate of fall in temperature of a **rising or a falling** air parcel adiabatically.
- **Adiabatic or adiabatically:** Heat **doesn't** enter or leave the system. All temperature changes are internal.
- Adiabatic Lapse rate is governed by **Gas law.**

Gas law

- According to gas law Pressure 'P' is directly proportional to Temperature 'T' when Volume 'V' is a constant.

Just for understanding

Example 1: A balloon

- When we blow air into a balloon, pressure increases but temperature doesn't increase due to proportionate increase in volume (here V is not constant). When excess air is blown, balloon bursts as it cannot with stand the pressure.

Example 2: Vehicle tube

- In a vehicle tube, volume remains constant. When air is blown, pressure increases and hence the temperature.
- We are usually advised not to have full blown tubes because when vehicle travels on a road, the friction between the tire and the road increases the temperature of the air in the tube. As temperature is directly proportional to pressure, increase in temperature leads to increase in pressure and at certain pressure threshold, the tire bursts.

The above examples explain the relation between Pressure, Temperature and Volume. They are both **non-adiabatic processes** as there is (will be) heat exchange between the system and the external environment.

Adiabatic Process: A Parcel of Rising or Falling Air

- An air bubble rises in water whereas stone sinks. This is obvious. The stone is denser (heavier than water) and it sinks whereas the air bubble is less denser (lighter than water) and it rises.
- Similarly, a parcel of air rises when it is less denser than the surrounding environment and it falls when its density becomes greater than the surrounding environment.

A Parcel of Rising Air

- When an air parcel is subjected to differential heating compared to the surrounding air, it becomes lighter (less denser) or heavier (more denser) depending on whether the air parcel is heated or cooled.
- When an air parcel receives more heat than the surrounding air, its temperature increases leading to an increase in volume

(Increase in Volume == Fall in Density). The air parcel becomes lighter than the surrounding air and it starts to rise. This process is **non-adiabatic** (there is heat exchange between the air parcel and the external environment).

- But when the air parcel starts to rise, the ambient pressure on it starts to fall [The atmospheric pressure decreases with height, so the pressure on the air parcel decreases with height]. With the fall in ambient pressure, the temperature falls and the volume increases. This is **adiabatic [**there is no heat exchange between the air parcel and the external environment. All the temperature changes are internal. Temperature changes are only due to change in pressure or volume or both**]**.
- This fall in temperature with the rising of the air parcel is called **Adiabatic Temperature Lapse.** And the rate at which it happens is called **Adiabatic Lapse Rate [This is Positive Adiabatic Lapse Rate as the Temperature is falling]**.

[Lapse Rate == fall in temperature with height. Adiabatic Lapse Rate == Fall in temperature in a rising parcel of air without losing any internal heat**]**

Rising of a parcel of air (and associated Positive Adiabatic Lapse Rate) is the first step in the formation of Thunderstorms, Tornadoes and Cyclones. [We will see this in detail in future posts]

A Parcel of Falling Air

- An air parcels falls to the lower levels of troposphere when it is cooled sufficiently.
- When an air parcel is in the upper levels, it gets cooled due to lower temperatures (Lapse Rate). It's volume falls and it's density increases. When it becomes more denser than the surroundings, it starts to fall.
- This also happens when an air parcel is in contact with cooler surfaces like mountain slopes. We will see more about this in temperature inversion.
- The beginning of fall is a non-adiabatic process as there is an exchange of heat between the air parcel and the surrounding environment.
- When an air parcel is falling, the atmospheric pressure acting on it will increase and its internal temperature will increase adiabatically. **[This is Negative Adiabatic Lapse Rate as the Temperature is rising]**.

Katabatic Wind is a hot dry wind that blows down a mountain slope. It is an example for a falling parcel of air in which the temperature changes happen adiabatically.

Adiabatic Lapse Rate in simple terms

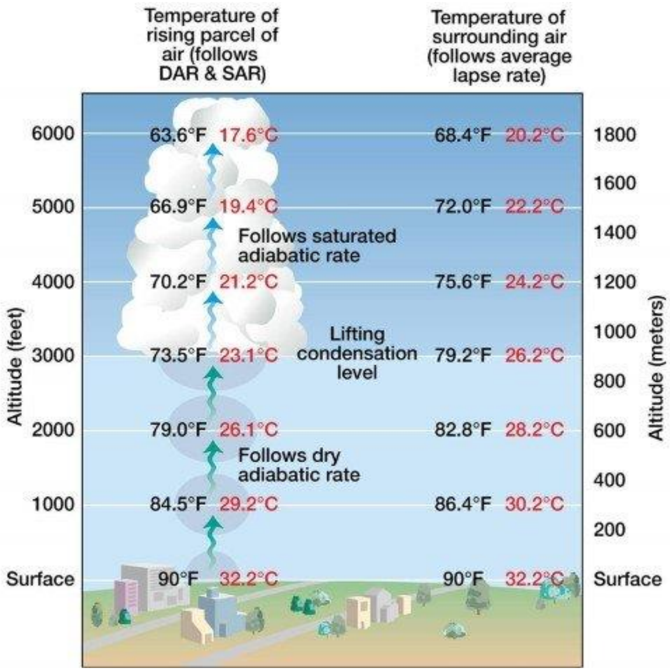
- Adiabatic change refers to the **change in temperature with pressure**.
- On descent through atmosphere, the lower layers are compressed under atmospheric pressure. As a result, the temperature increases.
- On ascent, the air expands as pressure 'decreases'. This expansion reduces the temperature and aids condensation of water vapour. Condensation of water vapour releases the **Latent Heat of Condensation** in the process.
- This latent heat of condensation is the **major driving force behind tropical cyclones, convectional rains.**

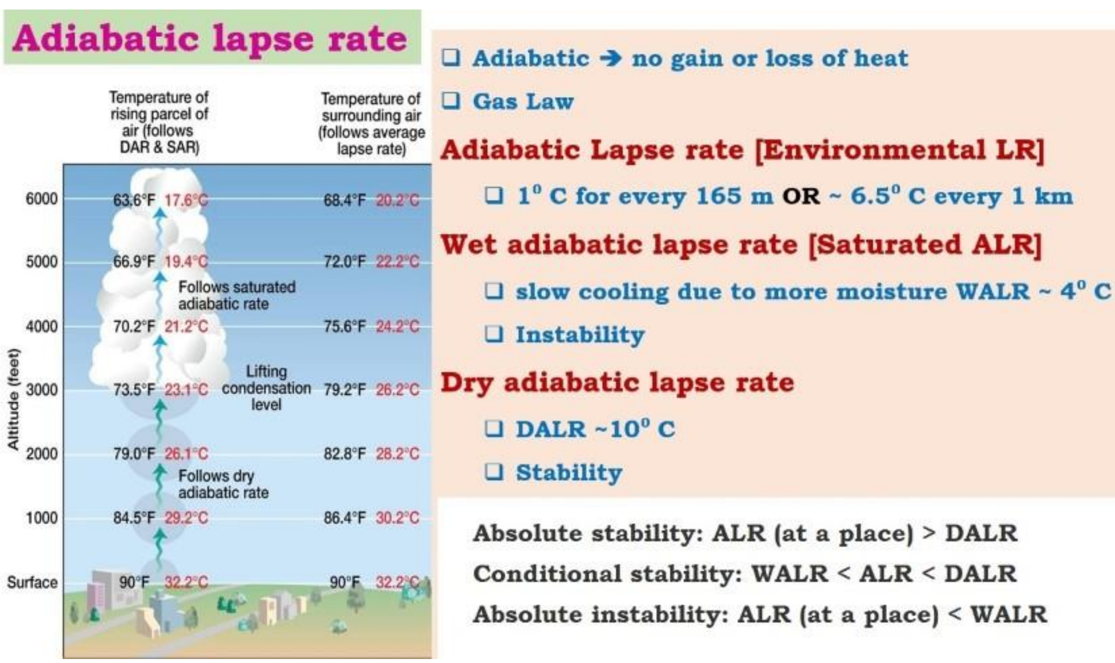
Wet and Dry Adiabatic Lapse rate

- Adiabatic lapse rates are usually differentiated as dry or wet (moist).

Dry Adiabatic Lapse rate

- The Dry Adiabatic Lapse Rate (DALR) is the rate of fall in temperature with altitude for a parcel of dry or unsaturated air (air with less moisture, to keep it simple) rising under adiabatic conditions.
- Unsaturated air has less than 100% relative humidity (we will study about Humidity in future posts).





[Saturated air == The air that cannot hold any more moisture. Its stomach is full Unsaturated air == It's stomach is not full. It can accommodate some more moisture.]

- When a rising air parcel has little moisture, condensation during upliftment is low, the latent heat of condensation released is low [Less additional heat from inside]. As a result, the fall in temperature with height is greater compared to Adiabatic Lapse Rate (normal parcel of air). [I have explained in detail in my videos]
- The dry adiabatic lapse rate for the Earth's atmosphere equals **9.8° C per kilometre**.
- Dry Adiabatic Lapse rate is mainly associated with **stable conditions [because it has less moisture].**

Wet Adiabatic Lapse rate

- When an air parcel that is saturated (stomach full) with water vapour rises, some of the vapour will condense and release latent heat [Additional Heat from inside]. This process causes the parcel to cool more slowly than it would if it were not saturated.
- The moist adiabatic lapse rate varies considerably because the amount of water vapour in the air is highly variable. The greater the amount of vapour, the smaller the adiabatic lapse rate [because the condensation process keeps on adding more latent heat of condensation]. On an average it is taken as **4° C per kilometre**.
- Wet Adiabatic Lapse rate is mainly associated with **unstable conditions [because it has more moisture].**
- As an air parcel rises and cools, it may eventually lose its moisture through condensation; its lapse rate then increases and approaches the dry adiabatic value.

Significance in meteorology

- The difference between the normal lapse rate in the atmosphere and the dry and moist adiabatic lapse rates determines the vertical stability of the atmosphere.

- For this reason, the lapse rate is of prime importance to meteorologists in forecasting certain types of cloud formations, the incidence of thunderstorms, and the intensity of atmospheric turbulence.

Weather conditions at different adiabatic lapse rates

1. LR (Lapse Rate) = Average Adiabatic Lapse Rate of **entire atmosphere** = 6 °C/km [**ALR of a place** may be greater than or lesser than the Laspe Rate of atmosphere, i.e, it may be less than or greater than 6 °C/km]
2. If ALR at a place is greater than 6 °C/km then it is called DALR = Less moisture than normal = more stable than normal.
3. If ALR at a place is lesser than 6 °C/km then it is called WALR = More moisture than normal = less stable than normal or instability.

Absolute stability: ALR (at a place) > DALR == Little moisture in the air parcel == It won't rain

Conditional stability: WALR < ALR < DALR == Normal moisture conditions == It may or may not rain

Absolute instability: ALR (at a place) < WALR == Excess moisture in the air parcel == It will rain violently.

Absolute stability: ALR (at a place) > DALR

- The above condition simply means that there is little moisture in air.
- When there is little moisture, condensation of water vapour is low, so latent of condensation released will be low, and the rising parcel of air gets cold quickly, and it falls to the ground once it becomes denser.
- So there will be no cloud formation and hence there will be no rain (thunderstorms).
- This simply means that the condition is stable.

Conditional stability: WALR < ALR < DALR

- The above condition simply means that there is enough moisture in air and there are chances of thunderstorms.
- When there is considerable moisture in the air parcel, condensation of water vapour will be reasonably high, so latent of condensation released will be adequate to drive a thunderstorm. The occurrence of thunderstorm depends on external factors. So the weather will be associated with conditional stability (it may rain or it may not rain)

Absolute instability: ALR (at a place) < WALR

- The above condition simply means that there is more moisture in air and there will be thunderstorms.
- When there is unusually high moisture in the air parcel, condensation of water vapour will be very high, so latent of condensation released will be great enough to drive a violent thunderstorm. So the weather will be associated with absolute instability.

Latent Heat of Condensation

- **Latent heat of condensation is the driving force behind all tropical cyclones.**

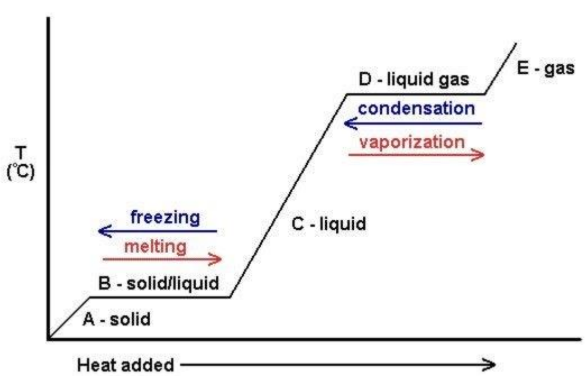
Latent Heat

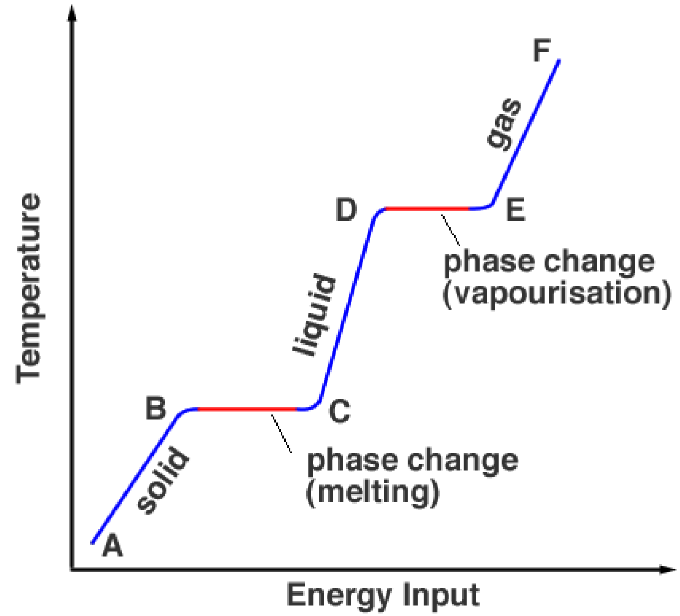
- It is the heat released or absorbed during phase change.
- Latent heat, characteristic amount of energy absorbed or released by a substance during a change in its physical state that occurs **without changing its temperature**.
- The latent heat associated with melting a solid or freezing a liquid is called the **heat of fusion**; that associated with vaporizing a liquid or a solid or condensing a vapour is called the **heat of vaporization**.

The latent heat is normally expressed as the amount of heat (in units of joules or calories) per mole or unit mass of the substance undergoing a change of state.

- For example, when a pot of water is kept boiling, the temperature remains at 100 °C until the last drop evaporates, because all the heat being added to the liquid is absorbed as latent heat of vaporization and carried away by the escaping vapour molecules.
- Similarly, while ice melts, it remains at 0 °C, and the liquid water that is formed with the latent heat of fusion is also at 0 °C.

Explanation





On X – axis: Heat supplied to the system.

On Y – Axis: Temperature change in the system.

- From the above graph, we can observe that there is no change in temperature in the system during change of state or phase change (solid to liquid, liquid to solid, liquid to gas and gas to liquid). Then where did the heat supplied go?
- Initially the heat supplied is used to raise the temperature of the system (A – B & C – D)
- During phase change, the heat supplied is consumed to turn water into liquid and then liquid into gas. So the heat supplied in used in phase change. Hence temperature of the system remains constant during phase change process. (B – C & D – E)
- But when gas turns into liquid or liquid into solid, heat is released. (this heat is the heat that was used during the phase change process)

So latent heat of condensation is the heat released when gases turn into liquid.

Vertical Distribution of Temperature

- The normal, lapse rate is uniform at a given level at all latitudes within the troposphere.

- At the Tropopause, the lapse rate stops at zero i.e. there is no change in temperature there.
- In the lower stratosphere, the lapse rate remains constant for some height, while higher temperatures exist over the poles because this layer is closer to earth at the poles.

Temperature Anomaly

- The difference between the mean temperature of a place and the mean temperature of its parallel (latitude) is called the **temperature anomaly or thermal anomaly**.
- The **largest anomalies occur in the northern hemisphere and the smallest in the southern hemisphere.**

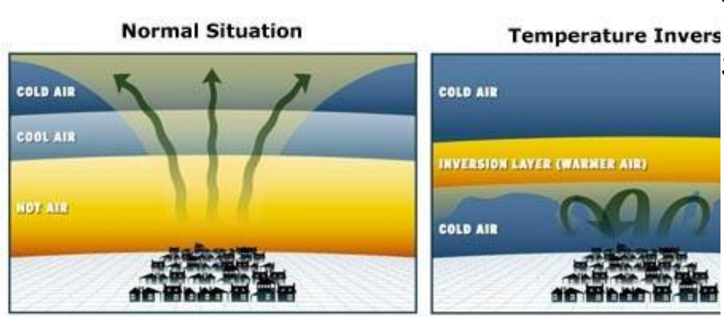
Temperature Inversion – Types – Effect on Weather.

UPSC mains 2013 question.

What do you understand by phenomenon of "temperature inversion" in meteorology? How does it affect weather and habitants of the place?

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**.

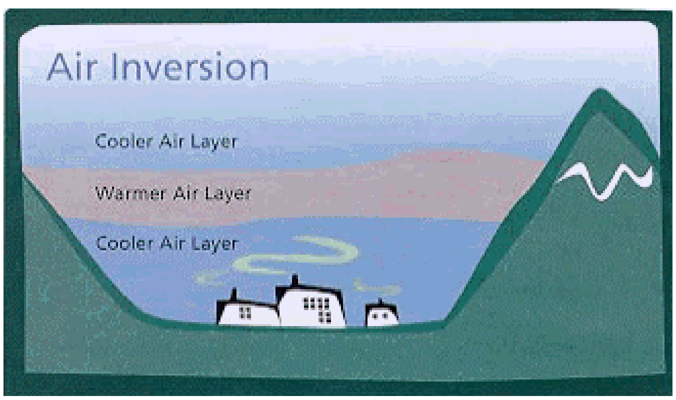
Ideal Conditions For Temperature Inversion

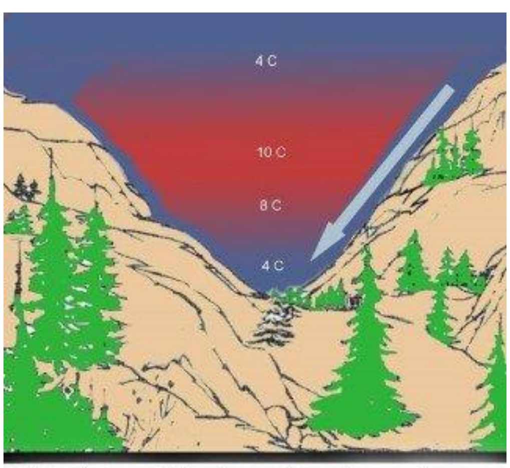
1. Long nights, so that the outgoing radiation is greater than the incoming radiation.
2. Clear skies, which allow unobstructed escape of radiation.
3. Calm and stable air, so that there is no vertical mixing at lower levels.

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.

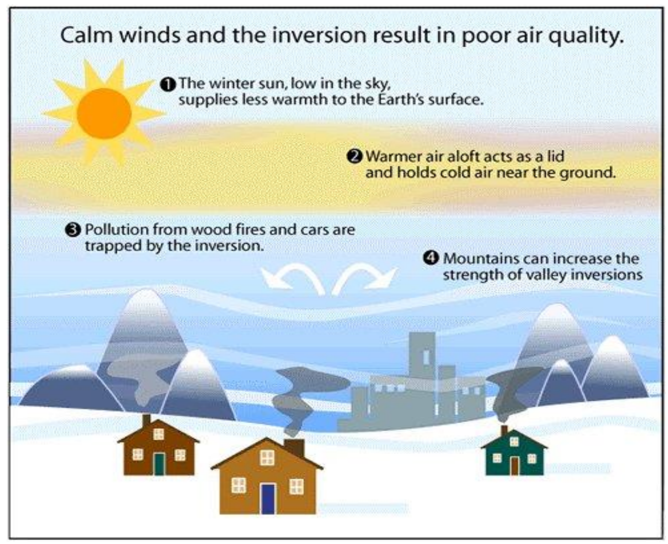


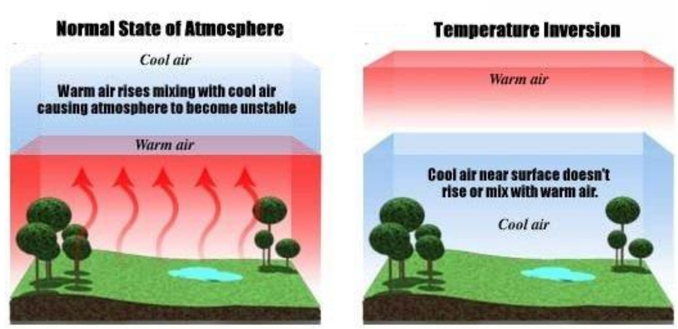


Zone of warm nighttime temperatures above a valley temperature inversion. (From Schroeder and Buck, 1970)

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.

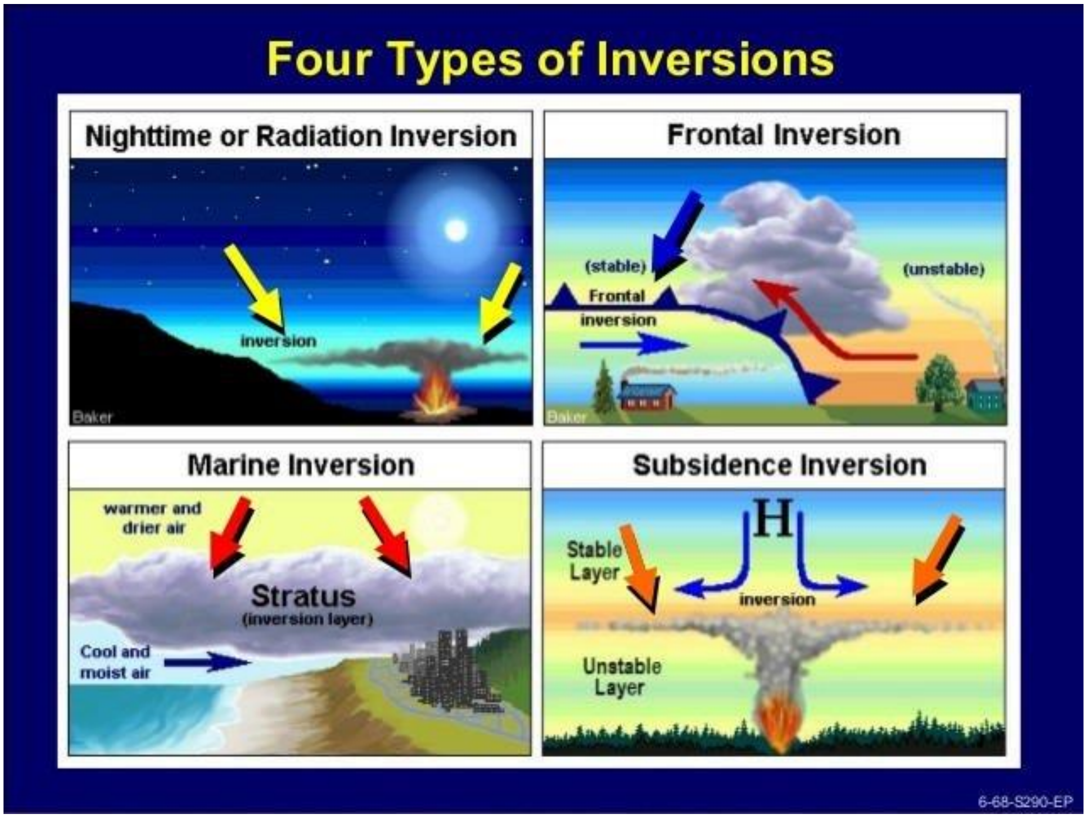




Subsidence Inversion (Upper Surface Temperature Inversion)

- 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 is 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.

Pressure Systems and Pressure Belts: Equatorial Low Pressure Belt or 'Doldrums', Sub-Tropical High Pressure Belts or 'Horse Latitudes', Sub-Polar Low Pressure Belts and Polar High Pressure Belts.

Pressure Systems

- Air expands when heated and gets compressed when cooled. This results in variations in the atmospheric pressure.
- The differences in atmospheric pressure causes the movement of air from high pressure to low pressure, setting the air in motion. Atmospheric pressure also determines when the air will rise or sink.
- Air in horizontal motion is wind. The wind redistributes the heat and moisture across latitudes, thereby, maintaining a constant temperature for the planet as a whole.
- The vertical rising of moist air forms clouds and bring precipitation.

Air Pressure

- Since air has mass, it also has weight. The pressure of air at a given place is defined as a force exerted in all directions by virtue of the weight of all the air above it.
- The weight of a column of air contained in a unit area from the mean sea level to the top of the atmosphere is called the atmospheric pressure. The atmospheric pressure is expressed in various units.

Measurement of Air Pressure

- Atmospheric pressure is the weight of the column of air at any given place and time. It is measured by means of an instrument called **barometer**.
- The units used by meteorologists for this purpose are called **millibars (mb).**
- **One millibar is equal to the force of one gram on a square centimeter. A pressure of 1000 millibars is equal to the weight of 1.053 kilograms per square centimeter.**
- In other words, *it will be equal to the weight of a column of mercury 75 cm high.*
- The normal pressure at sea level is taken to be about ***76 centimeters (1013.25 millibars).***

Vertical Variation of Pressure

- In the lower atmosphere the pressure decreases rapidly with height.
- At the height of Mt. Everest, the air pressure is about two-thirds less than what it is at the sea level.
- The decrease in pressure with altitude, however, is not constant. Since the factors controlling air density – temperature, amount of water vapour and gravity are variable, there is no simple relationship between altitude and pressure.
- In general, the atmospheric pressure decreases on an average at the rate of about 34 millibars every 300 metres of height.

Table 10.1 : Standard Pressure and Temperature at Selected Levels

Level	*Pressure in mb*	*Temperature °C*
Sea Level	1,013.25	15.2
1 km	898.76	8.7
5 km	540.48	–17. 3
10 km	265.00	– 49.7

- The vertical pressure gradient force is much larger than that of the horizontal pressure gradient. But, it is generally balanced by a nearly equal but opposite **gravitational force**. Hence, we do not experience strong upward winds.
- Due to gravity the air at the surface is denser and hence has higher pressure. Since air pressure is proportional to **density as well as temperature**, it follows that a change in either temperature or density will cause a corresponding change in the pressure.
- The pressure decreases with height. At any elevation it varies from place to place and its variation is the primary cause of air motion, i.e. wind which moves from high pressure areas to low pressure areas.

- **A rising pressure indicates fine, settled weather, while a falling pressure indicates unstable and cloudy weather.**

Horizontal Distribution of Pressure

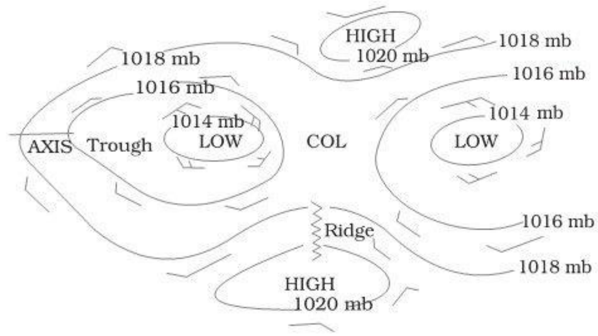
- Small differences in pressure are highly significant in terms of the wind direction and velocity. Horizontal distribution of pressure is studied by drawing isobars at constant levels.
- **Isobars** are lines connecting places having equal pressure. In order to eliminate the effect of altitude on pressure, it is measured at any station after being reduced to sea level for purposes of comparison.
- The spacing of isobars expresses the rate and direction of pressure changes and is referred to as **pressure gradient.**
- Close spacing of isobars indicates a steep or strong pressure gradient, while wide spacing suggests weak gradient. The pressure gradient may thus be defined as the decrease in pressure per unit distance in the direction in which the pressure decreases most rapidly.
- There are distinctly identifiable zones of homogeneous horizontal pressure regimes or **'pressure belts'.** On the earth's surface, there are in all seven pressure belts.
- The seven pressure belts are :

1. ***equatorial low,***
2. ***the sub-tropical highs,***
3. ***the sub-polar lows, and***
4. ***the polar highs.***

- Except the equatorial low, all others form matching pairs in the northern and southern hemispheres.

Closed Isobars or Closed Pressure centers

- Low pressure system is enclosed by one or more isobars with the lowest pressure in the centre. High-pressure system is also enclosed by one or more isobars with the highest pressure in the centre.

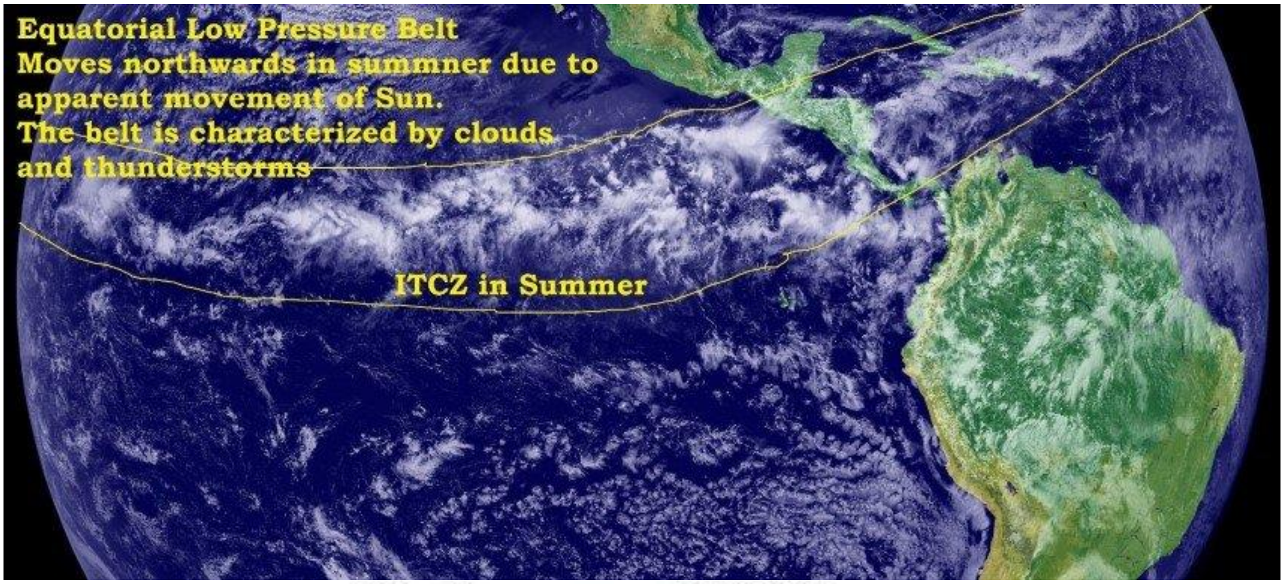


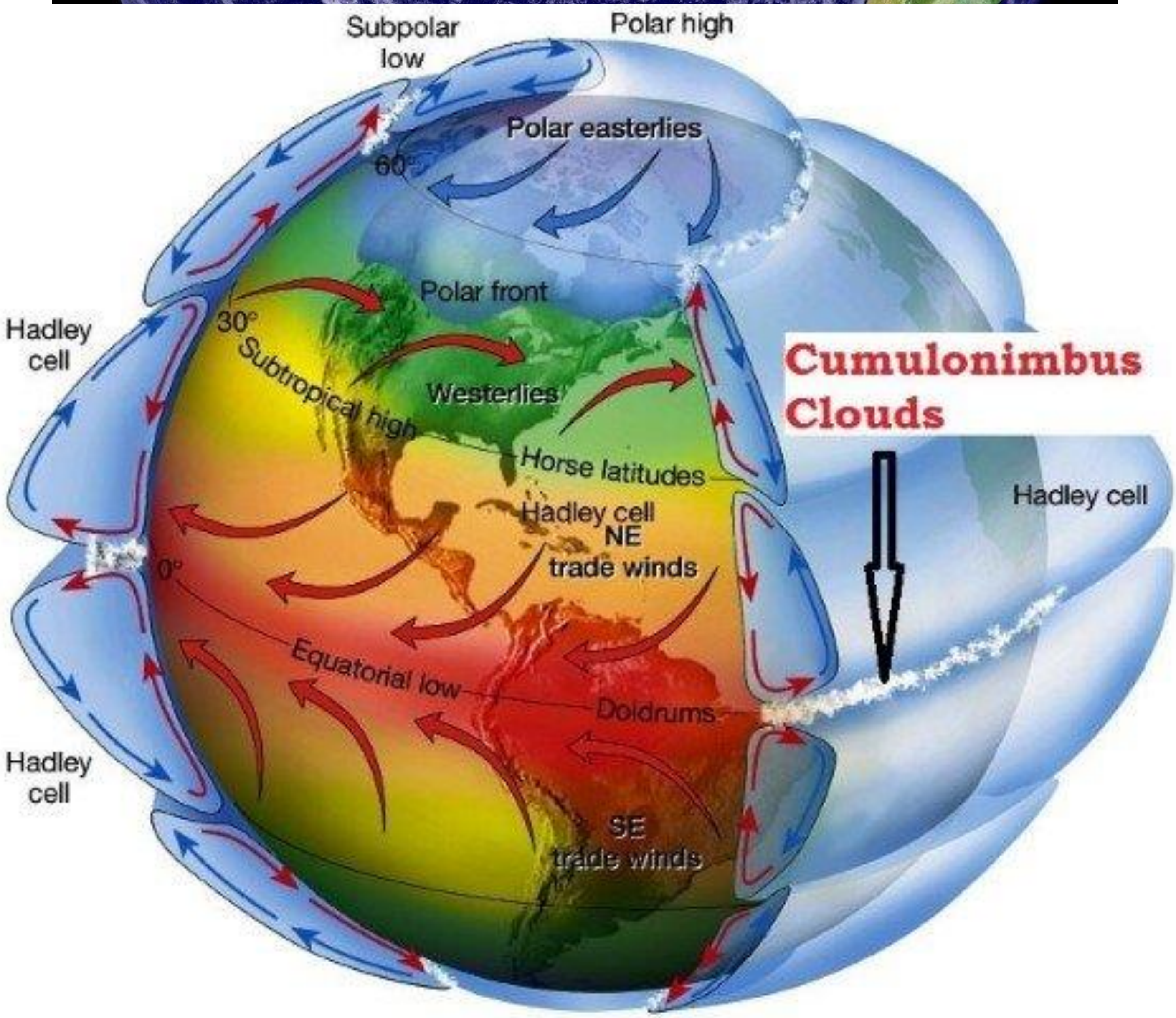
World Distribution of Sea Level Pressure

- The atmosphere exerts a pressure of **1034 gm per square cm** at sea level. This amount of pressure is exerted by the atmosphere at sea level on all animals, plants, rocks, etc.
- Near the equator the sea level pressure is low and the area is known as **equatorial low**. Along 30° N and 30° S are found the **high-pressure areas known as the subtropical highs.** Further pole wards along 60° N and 60° S, the **low-pressure belts are termed as the sub polar lows.** Near the poles the **pressure is high and it is known as the polar high.**
- These pressure belts are **not permanent** in nature. They oscillate with the apparent movement of the sun. In the northern hemisphere in winter they move southwards and in the summer northwards.

Equatorial Low Pressure Belt or 'Doldrums'

- Lies between **10°N and 10°S latitudes.**
- Width may vary between 5°N and 5°S and 20°N and 20°S.
- This belt happens to be the **zone of convergence of trade winds** from two hemispheres from sub-tropical high pressure belts.
- This belt is also called the **Doldrums**, because of the **extremely calm air movements.**
- The position of the belt varies with the apparent movement of the Sun.





Formation

- As this region lies along the equator, it receives highest amount of insolation.

- Due to intense heating, air gets warmed up and rises over the equatorial region (convection).
- Whenever there is vertically upward movement of air, the region at the surface will be at low pressure. Thus the belt along the equator is called equatorial low pressure belt.

Climate

- This belt is characterized by **extremely low pressure** with **calm conditions**.
- This is because of the **absence of Surface winds** since winds approaching this belt begin to rise near its margin. Thus, **only vertical currents are found**.
- As the larger part of the low pressure belt passes along the oceans, the winds obtain huge amount of moisture.
- Vertical winds (convection) carrying moisture form **cumulonimbus clouds** and lead to **thunderstorms (convectional rainfall).**
- **Inspite of high temperatures, cyclones are not formed at the equator because of 'zero' coriolis force.** (we will see more later)

Sub-Tropical High Pressure Belt or Horse Latitudes

- The sub-tropical highs extend from near the tropics to about **35°N and S.**

Formation

- After saturation (complete loss of moisture) at the ITCZ, the air moving away from equatorial low pressure belt in the upper troposphere becomes dry and cold.
- This dry and cold wind subsides at 30°N and S. So the high pressure along this belt is due to **subsidence of air coming from the equatorial region** which descends after becoming heavy.
- The high pressure is also due to the blocking effect of air at upper levels because of the **Coriolis force.**

Climate

- The **subsiding air is warm and dry, therefore, most of the deserts are present along this belt, in both hemispheres**.
- A calm condition **(anticyclonic)** with feeble winds is created in this high pressure belt.
- The descending air currents feed the winds blowing towards adjoining low pressure belts.
- This belt is **frequently invaded by tropical and extra-tropical disturbances**.

Horse Latitudes

- The corresponding latitudes of sub-tropical high pressure belt are called **horse latitudes.**
- In early days, the sailing vessels with cargo of horses found it difficult to sail under calm conditions of this high pressure belt.
- They used to throw horses into the sea when fodder ran out. Hence the name horse latitudes.

Question mains 2013

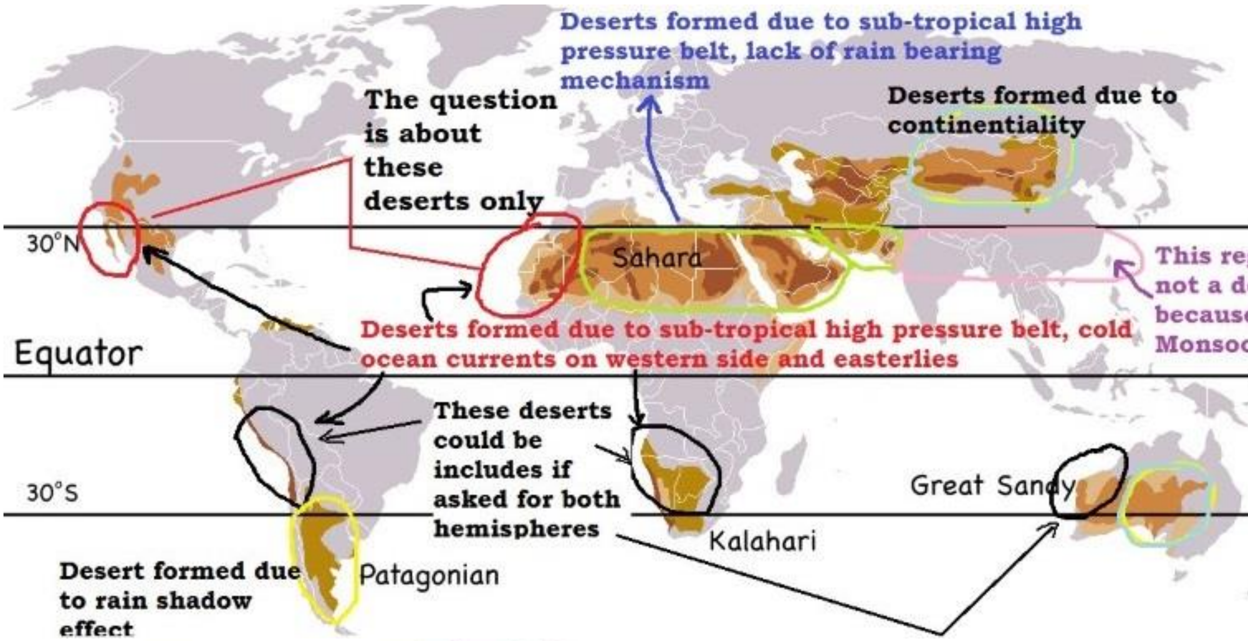
Major hot deserts in northern hemisphere are located between 20-30 degree north and on the western side of the continents. Why?

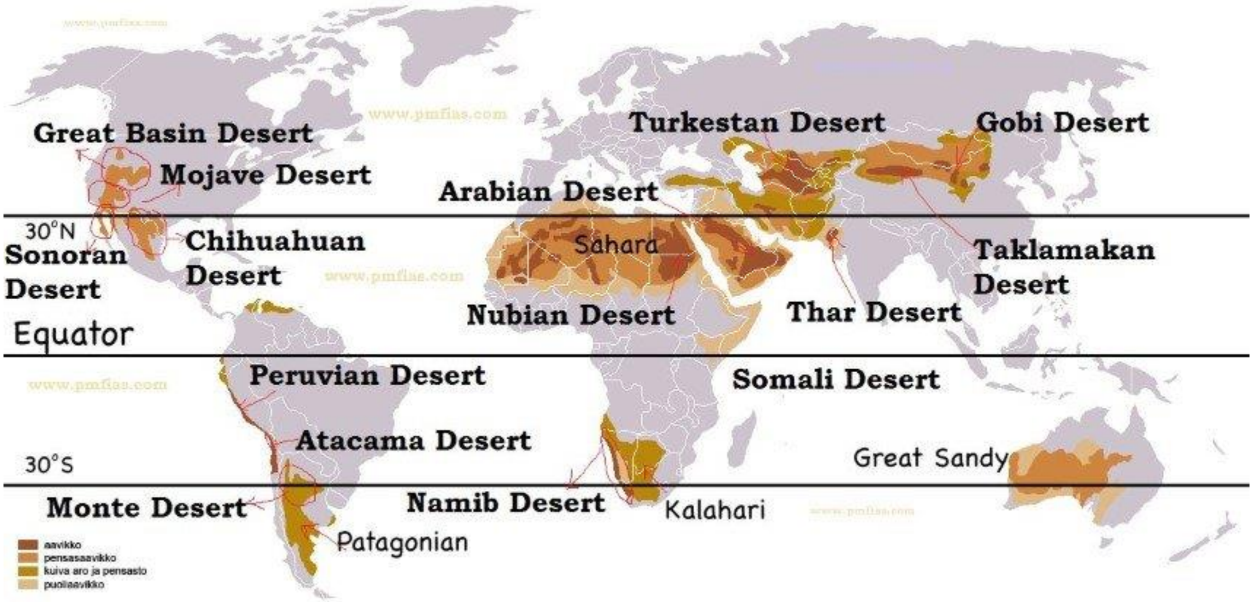
Why between 20 – 30 degree?

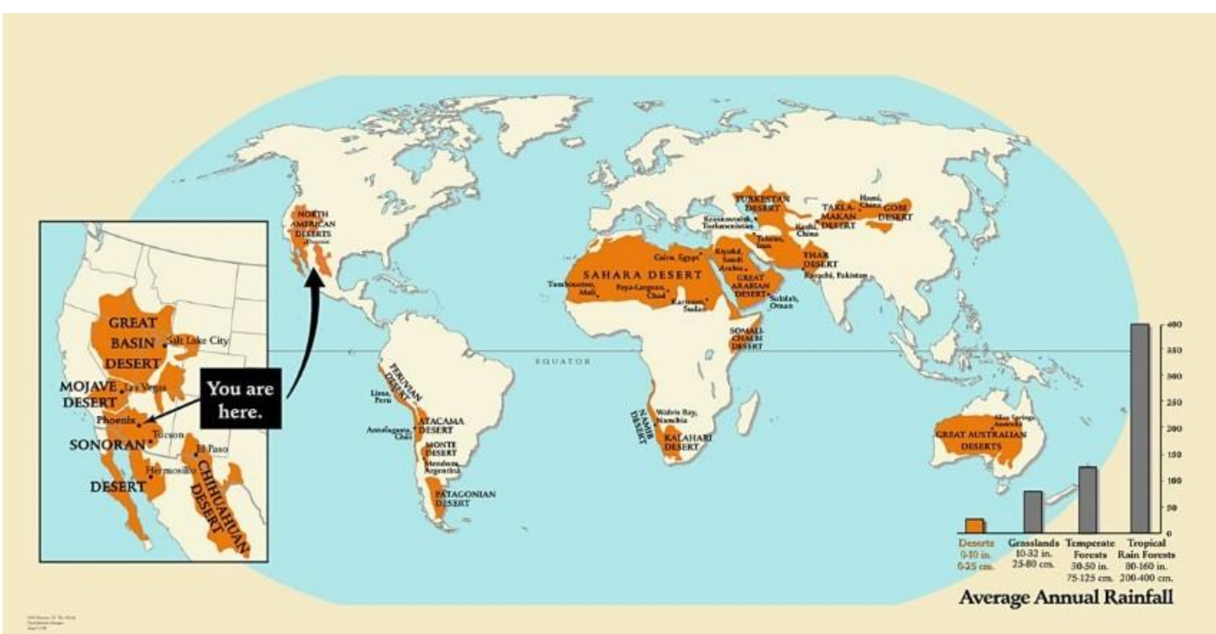
- Answer: The ***subsiding air is warm and dry, therefore, most of the deserts are present along this belt, in both hemispheres***.

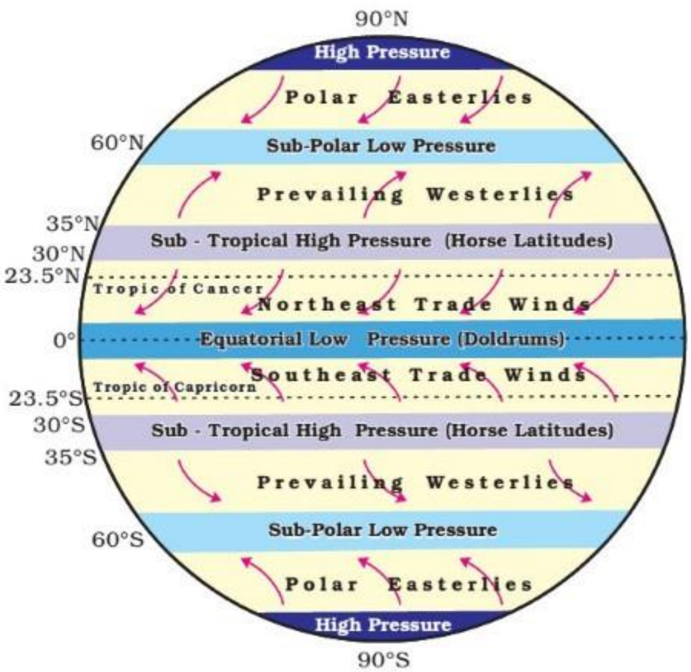
Why on western side of the continents?

- We will get answer for this while studying ocean currents.


Deserts formed due to sub-tropical high pressure belt, lack of rain bearing mechanism
The question is about these deserts only
Deserts formed due to continentiality
30°N
Sahara
This region is not a desert because of Monsoons
Deserts formed due to sub-tropical high pressure belt, cold ocean currents on western side and easterlies
Equator
These deserts could be includes if asked for both hemisperes
30°S
Great Sandy
Kalahari
Desert formed due to rain shadow effect
Patagonian


Great Basin Desert
Mojave Desert
Turkestan Desert
Gobi Desert
Arabian Desert
30°N
Sonoran Desert
Chihuahuan Desert
Sahara
Taklamakan Desert
Nubian Desert
Thar Desert
Equator
Peruvian Desert
Somali Desert
Atacama Desert
30°S
Great Sandy
Monte Desert
Namib Desert
Kalahari
Patagonian
aavikko
pensasaavikko
kuiva aro ja pensasto
puoliaavikko


GREAT BASIN DESERT
Salt Lake City
MOJAVE DESERT
Las Vegas
You are here.
Phoenix
SONORAN DESERT
Tucson
El Paso
Hermosillo
CHIHUAHUAN DESERT
SAHARA DESERT
EQUATOR
Average Annual Rainfall



Major Pressure Belts and Wind System

Sub-Polar Low Pressure Belt

- Located between **45°N and S latitudes** and the **Arctic and the Antarctic circles (66.5° N and S latitudes).**
- Owning to low temperatures in these latitudes the sub polar low pressure belts are not very well pronounced year long.
- On long-term mean climatic maps, the sub polar low-pressure belts of the northern hemisphere are grouped into two centers of atmospheric activity: the **Iceland low** and the **Aleutian depression (Aleutian low).**
- Such belts in the southern hemisphere surround the periphery of Antarctica and are not as well differentiated.

Formation

- These are **dynamically produced** due to

1. **Coriolis Force** produced by **rotation of the earth on its axis, and**.
2. **Ascent of air as a result of convergence of westerlies and polar easterlies (we will more about these in next topic – wind systems).**

- Sub polar low-pressure belts are mainly encountered above **oceans.**

Seasonal behavior

- During winter, because of a high contrast between land and sea, this belt is broken into two distinct low centers – one in the vicinity of the Aleutian Islands and the other between Iceland and Greenland.
- During summer, a lesser contrast results in a more developed and regular belt.

Climate

- The area of contrast between cold and warm air masses produces **polar jet streams** which encircles the earth at 60 degrees latitudes and is focused in these low pressure areas.

Due to a great contrast between the temperatures of the winds from sub-tropical and polar source regions, extra tropical cyclonic storms or lows' (temperate cyclones or frontal cyclones) are produced in this region.

Polar High Pressure Belt

- The polar highs are small in area and extend around the poles.
- They lie around poles between 80 – 90° N and S latitudes.

Formation

- The air from sub-polar low pressure belts after saturation becomes dry. This dry air becomes cold while moving towards poles through upper troposphere.
- The cold air (heavy) on reaching poles subsides creating a high pressure belt at the surface of earth.

Climate

- The lowest temperatures are found over the poles.

Pressure belts in July

- In the northern hemisphere, during summer, with the apparent northward shift of the sun, the thermal equator (belt of highest temperature) is located north of the geographical equator.

- The pressure belts shift slightly north of their annual average locations.

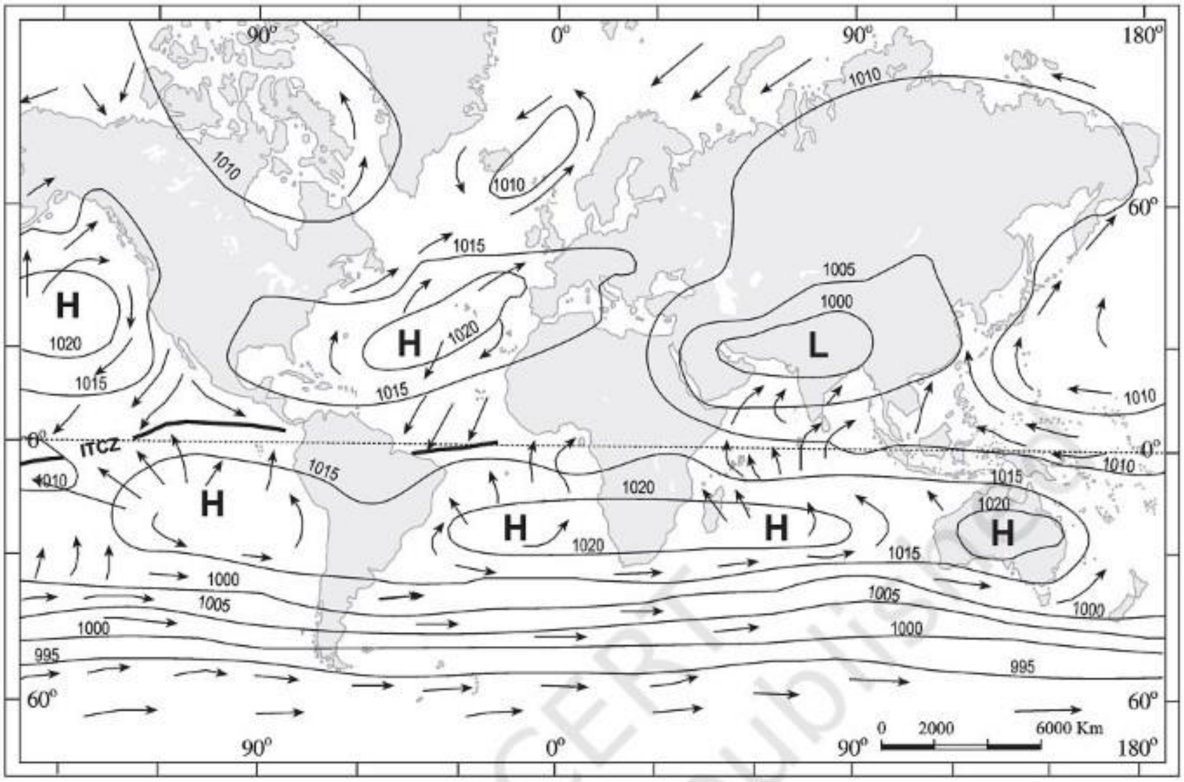


Figure 10.3 : Distribution of pressure (in millibars) — July

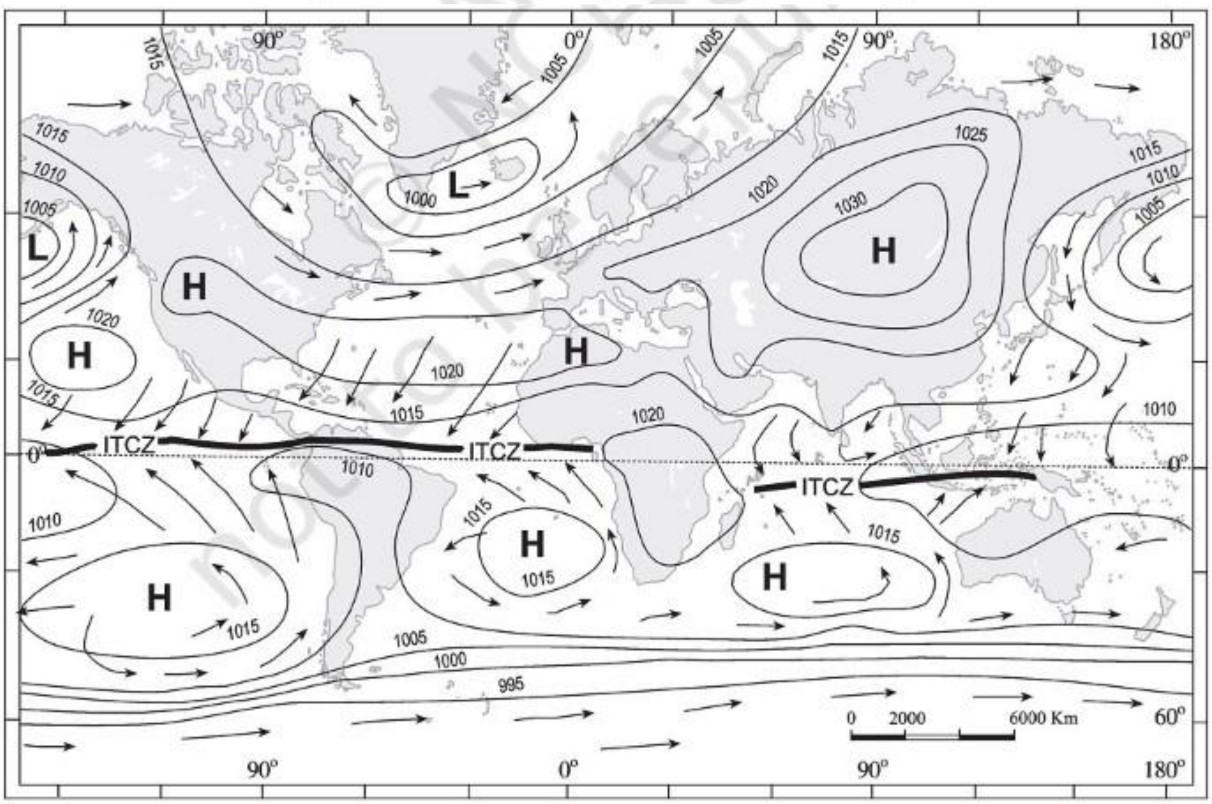


Figure 10.2 : Distribution of pressure (in millibars) — January

Pressure belts in January

- During winter, these conditions are completely reversed and the pressure belts shift south of their annual mean locations. Opposite conditions prevail in the southern hemisphere. The amount of shift is, however, less in the southern hemisphere due to predominance of water.
- Similarly, distribution of continents and oceans have a marked influence over the distribution of pressure. In winter, the continents are cooler than the oceans and tend to develop high pressure centres, whereas in summer, they are relatively warmer and develop low pressure. It is just the reverse with the oceans.

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).**

Example

- After saturation (complete loss of mosture) at the ITCZ, the air moving away from equatorial low pressure belt in the upper troposphere becomes dry and cold. This dry and cold wind subsides at 30°N and S.
- So the high pressure along this belt is due to **subsidence of air coming from the equatorial region** which descends after becoming heavy.
- The **rate of deflection increases with the distance from the equator (Coriolis force).** As a result, by the time the poleward directed winds reach 25° latitude, they are deflected into a nearly west-to-east flow. It produces a **blocking effect** and the air piles up. This causes a general subsidence in the areas between the tropics and 35°N and S, and they develop into high pressure belts.
- The location of pressure belts is further affected by differences in net radiation resulting from apparent movement of the sun and from variations in heating of land and water surfaces.
- Thus formation of **sub-tropical high** and **sub-polar low pressure belts** are due to **dynamic factors** like **pressure gradient forces, apparent movement of sun** and rotation of the earth **(Coriolis force)**

In this post: Wind Movement – Factors Affecting Wind movement: Pressure Gradient Force, Coriolis Force, Frictional Force, Centripetal Acceleration and Geostrophic Wind. Coriolis effect: Causes, Impact and Myth about Coriolis Effect.

Factors affecting Wind Movement

- Wind == horizontal movement of air
- Currents == vertical movement of air.
- Winds balance uneven distribution of pressure globally.
- Winds help in transfer of heat, moisture etc. from one place to another.
- Sun is the ultimate force that drives winds. Pressure differences force winds to flow from high pressure are to low pressure area. Pressure differences in turn are caused by unequal heating of the earth's surface by solar radiation.
- The wind at the surface experiences **friction**. In addition, rotation of the earth also affects the wind movement. The force exerted by the rotation of the earth is known as the **Coriolis force.**

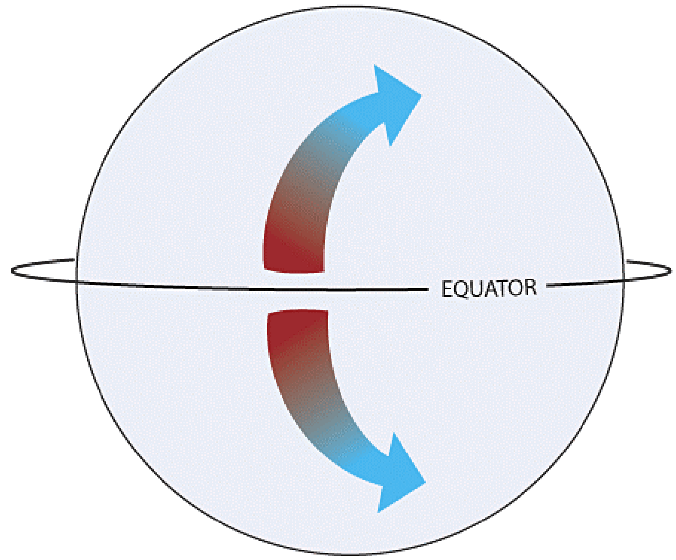
- Thus, the horizontal winds near the earth surface respond to the combined effect of three forces – the **pressure gradient force**, the **frictional force** and the **Coriolis force.**
- In addition, the **gravitational force** acts downwards. **Centripetal acceleration** produces a circular pattern of flow around centers of high and low pressure.

Pressure Gradient Force and Wind Movement

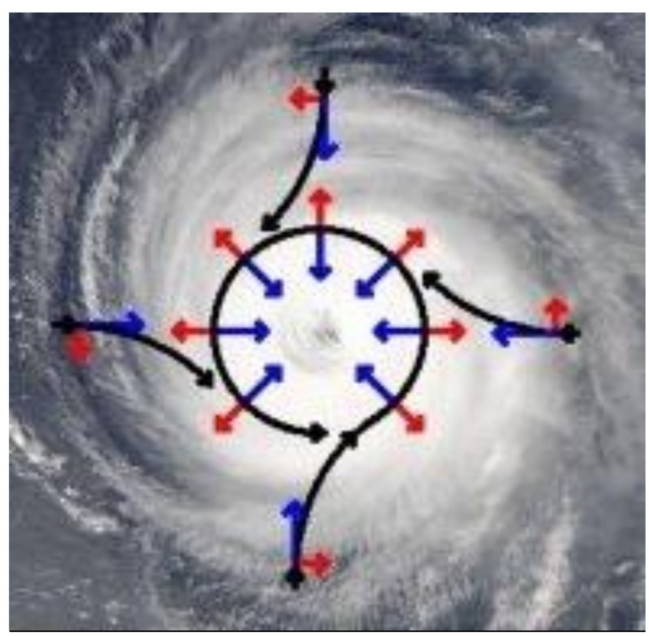
- The differences in atmospheric pressure produces pressure gradient force.
- The rate of change of pressure with respect to distance is the pressure gradient.
- Pressure Gradient Force operates from the high pressure area to a low pressure area and causes wind movement.
- *The pressure gradient is strong where the isobars are close to each other and is weak where the isobars are apart.*
- Since a closely spaced gradient implies a steep pressure change, it also indicates a strong wind speed.
- The wind direction follows the direction of change of pressure, i.e. **perpendicular to the isobars.**

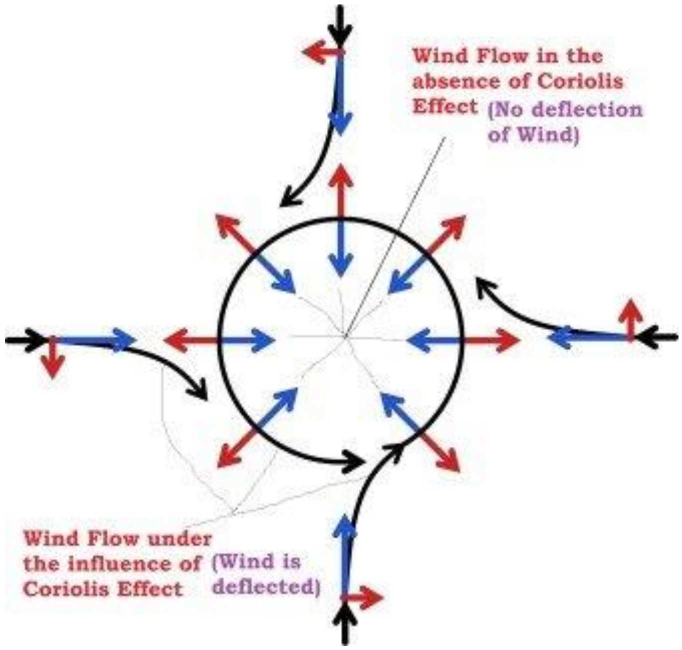
Coriolis Force and Wind Movement

- The rotation of the earth about its axis affects the direction of the wind. This force is called the Coriolis force. It has great impact on the direction of wind movement.
- Due to the earth's rotation, winds do not cross the isobars at right angles as the pressure gradient force directs, but get deflected from their original path.
- This deviation is the result of the earth's rotation and is called the Coriolis effect or Coriolis force.
- Due to this effect, **winds in the northern hemisphere get deflected to the right** of their path and those in the **southern hemisphere to their left**, following **Farrell's Law** (the law that wind is deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, derived from the application of the Coriolis effect to air masses).



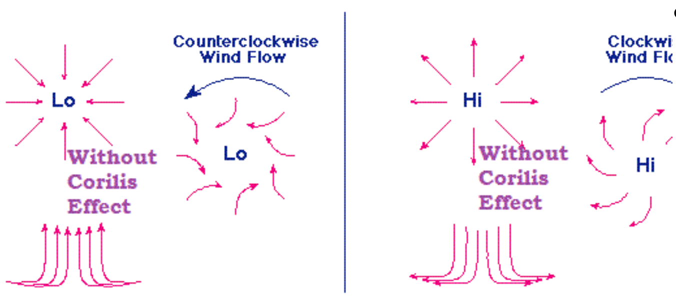
- This deflection force does not seem to exist until the air is set in motion and increases with **wind velocity, air mass** and an **increase in latitude**.
- The Coriolis force acts **perpendicular to the pressure gradient force (pressure gradient force is perpendicular to an isobar)**
- As a result of these two forces operating perpendicular to each other, in the low-pressure areas the wind blows around it **(cyclonic conditions).**





Why are there no tropical cyclones at the equator?

- The Coriolis force is directly proportional to the angle of latitude. It is **maximum at the poles and is absent at the equator.**
- At the **equator (Coriolis force is zero)** wind blows perpendicular to the isobars. The low pressure gets filled instead of getting intensified i.e., there is no spiraling of air due to zero Coriolis effect. The winds directly gets uplifted vertically to form thunderstorms.



Frictional Force and Wind Movement

- The irregularities of the earth's surface offer resistance to the wind movement in the form of friction.
- It affects the speed of the wind. It is greatest at the surface and its influence generally extends up to an elevation of 1 - 3 km. Over the sea surface the friction is minimal.
- Over uneven terrain, however, due to high friction, the wind direction makes high angles with, isobars and the speed gets retarded.

Centripetal Acceleration

- It acts only on air that is flowing around centers of circulation.
- Centripetal acceleration creates a force directed at right angles to the wind movement and inwards towards the centers of rotation (e.g., low and high pressure centers).
- This force produces a circular pattern of flow around centers of high and low pressure.
- Centripetal acceleration is more important for circulations smaller than the mid-latitude cyclone.

Pressure and Wind: Geostrophic Wind

- The velocity and direction of the wind are the net result of the wind generating forces.
- The winds in the upper atmosphere, 2 - 3 km above the surface, are free from frictional effect of the surface and are controlled by the **pressure gradient** and the **Coriolis force.**
- When isobars are straight and when there is no friction, the pressure gradient force is balanced by the Coriolis force and the resultant wind blows parallel to the isobar. This wind is known as the **geostrophic wind.**

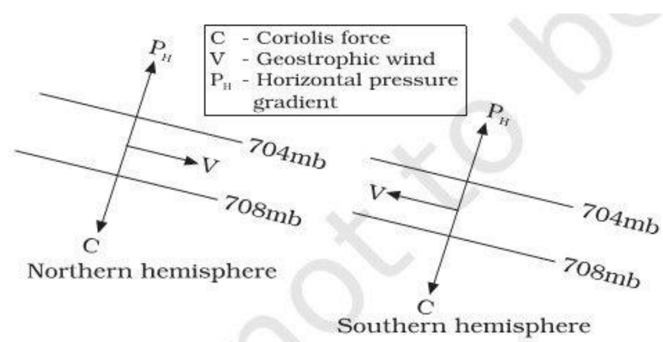


Figure 10.4 : Geostropic Wind

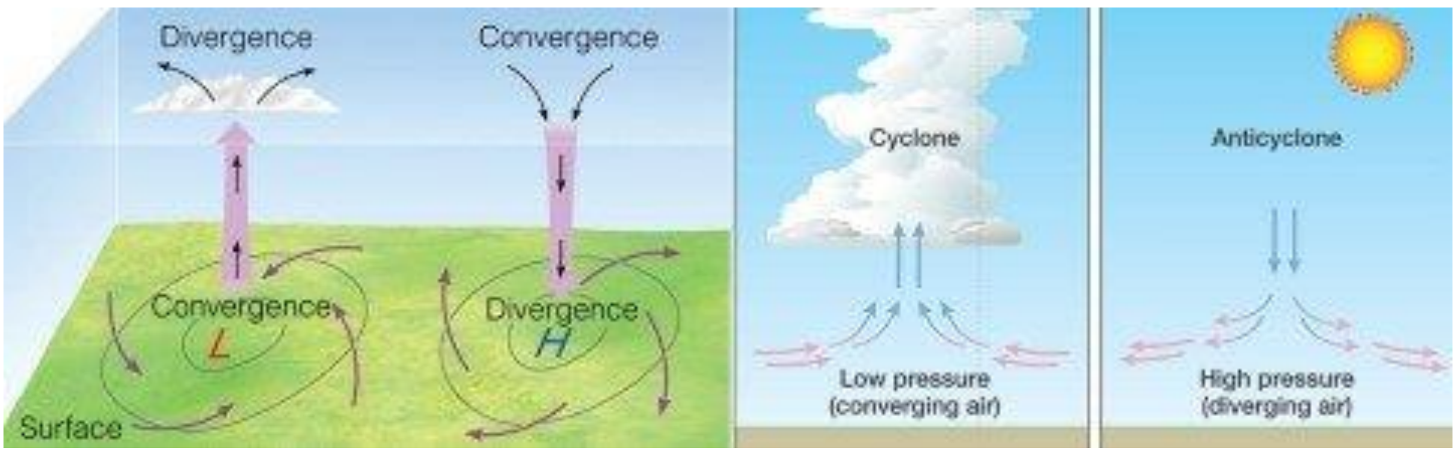
- The wind movement around a low is called **cyclonic circulation**. Around a high it is called **anti cyclonic circulation**. The direction of winds around such systems changes according to their location in different hemispheres.

Table 10.2 : Pattern of Wind Direction in Cyclones and Anticyclones

Pressure System	*Pressure Condition at the Centre*	*Pattern of Wind Direction*	
		Northern Hemisphere	*Southern Hemisphere*
Cyclone	Low	Anticlockwise	Clockwise
Anticyclone	High	Clockwise	Anticlockwise

The wind movement or wind circulation at the earth's surface around low and high on many occasions is closely related to the wind circulation at higher level. Generally, over low pressure area the air will converge and rise. Over high pressure area the air will subside from above and diverge at the surface.

- Apart from convergence, some eddies, convection currents, orographic uplift and uplift along fronts cause the rising of air, which is essential for the formation of clouds and precipitation. (more about this later)



More about Coriolis effect

- The Coriolis effect is the **apparent deflection of objects** (such as airplanes, wind, missiles, sniper gun bullets and ocean currents) moving in a straight path **relative** to the earth's surface.
- Its strength is **proportional to the speed of the earth's rotation** at different latitudes but it has an impact on moving objects across the globe.
- The **"apparent"** portion of the Coriolis effect's definition is also important to take into consideration.
- This means that from the object in the air (i.e. an airplane) the earth can be seen rotating slowly below it. From the earth's surface that same object appears to curve off of its course. The object is not actually moving off of its course but this just appears to be happening because the earth's surface is rotating beneath the object.

Causes of the Coriolis Effect

- The main cause of the Coriolis effect is the **earth's rotation**. As the earth spins in a counter-clockwise direction on its axis anything flying or flowing over a long distance above its surface appears to be deflected.
- This occurs because as something moves freely above the earth's surface, the earth

is moving east under the object at a faster speed.

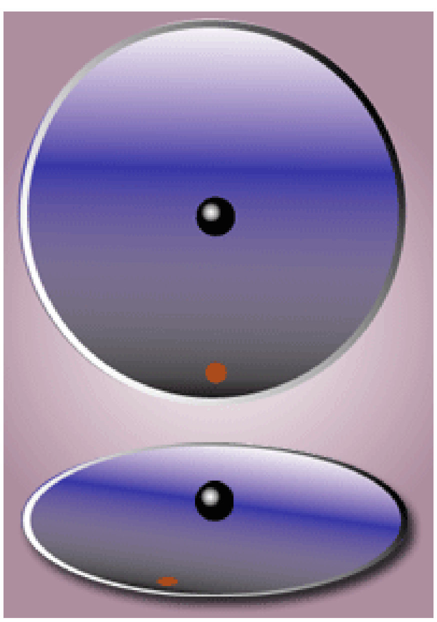
- As latitude increases and the speed of the earth's rotation decreases, Coriolis effect increases.
- A plane flying along the equator itself would be able to continue flying on the equator without any apparent deflection. A little to the north or south of the equator, the plane would be deflected.
- In addition to the speed of the earth's rotation and latitude, the faster the object itself is moving, the more deflection there will be.

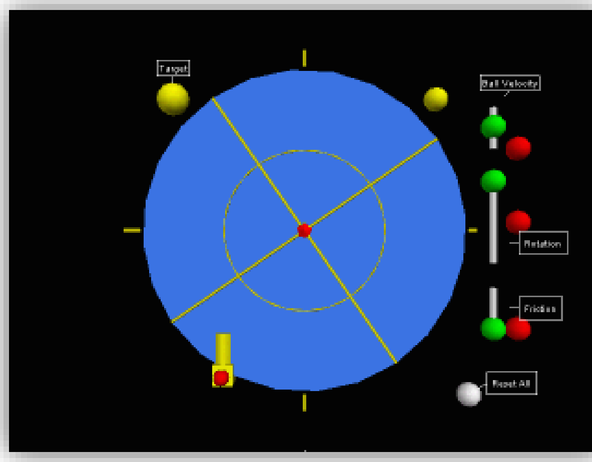
Impacts of the Coriolis Effect

- Some of the most important impacts of the Coriolis effect in terms of geography are the deflection of winds and currents in the ocean. It also has a significant effect on man-made items like planes and missiles.

Myth about Coriolis Effect

- One of the biggest misconceptions associated with the Coriolis effect is that it causes the rotation of water down the drain of a sink or toilet. This is not truly the cause of the water's movement. The water itself is simply moving too fast down the drain to allow for the Coriolis effect to have any significant impact.





Gif Image

In This Post: Winds - General circulation of the atmosphere: Hadley Cell, Ferrel Cell, Polar Cell and Walker Cell.

Classification of Winds: Permanent winds or Primary winds or Prevailing winds or Planetary Winds, Secondary or Periodic Winds and Local winds

Primary or Prevailing Winds: The Trade Winds, The Westerlies, The Polar easterlies

Secondary or Periodic Winds: Monsoons, Land Breeze and Sea Breeze, and Valley Breeze and Mountain Breeze

Tertiary or Local Winds: Loo, Foehn or Fohn, Chinook, Mistral and Sirocco.

General circulation of the atmosphere

- The pattern of planetary winds depend on:

(i) latitudinal variation of atmospheric heating;
(ii) emergence of pressure belts;
(iii) the migration of belts following apparent path of the sun;
(iv) the distribution of continents and oceans;
(v) 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.**

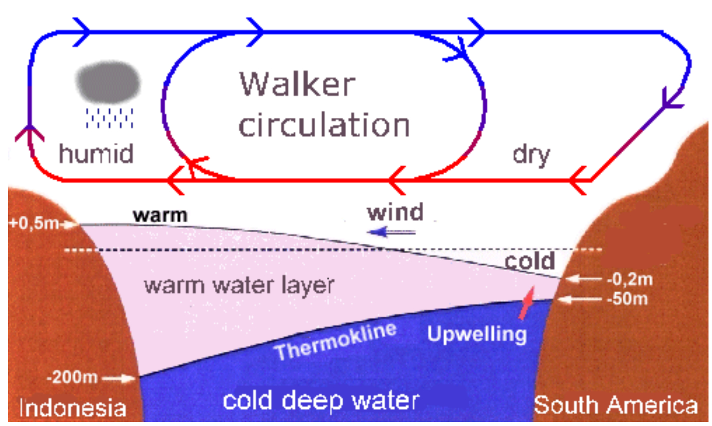
Polar Cell

- 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)



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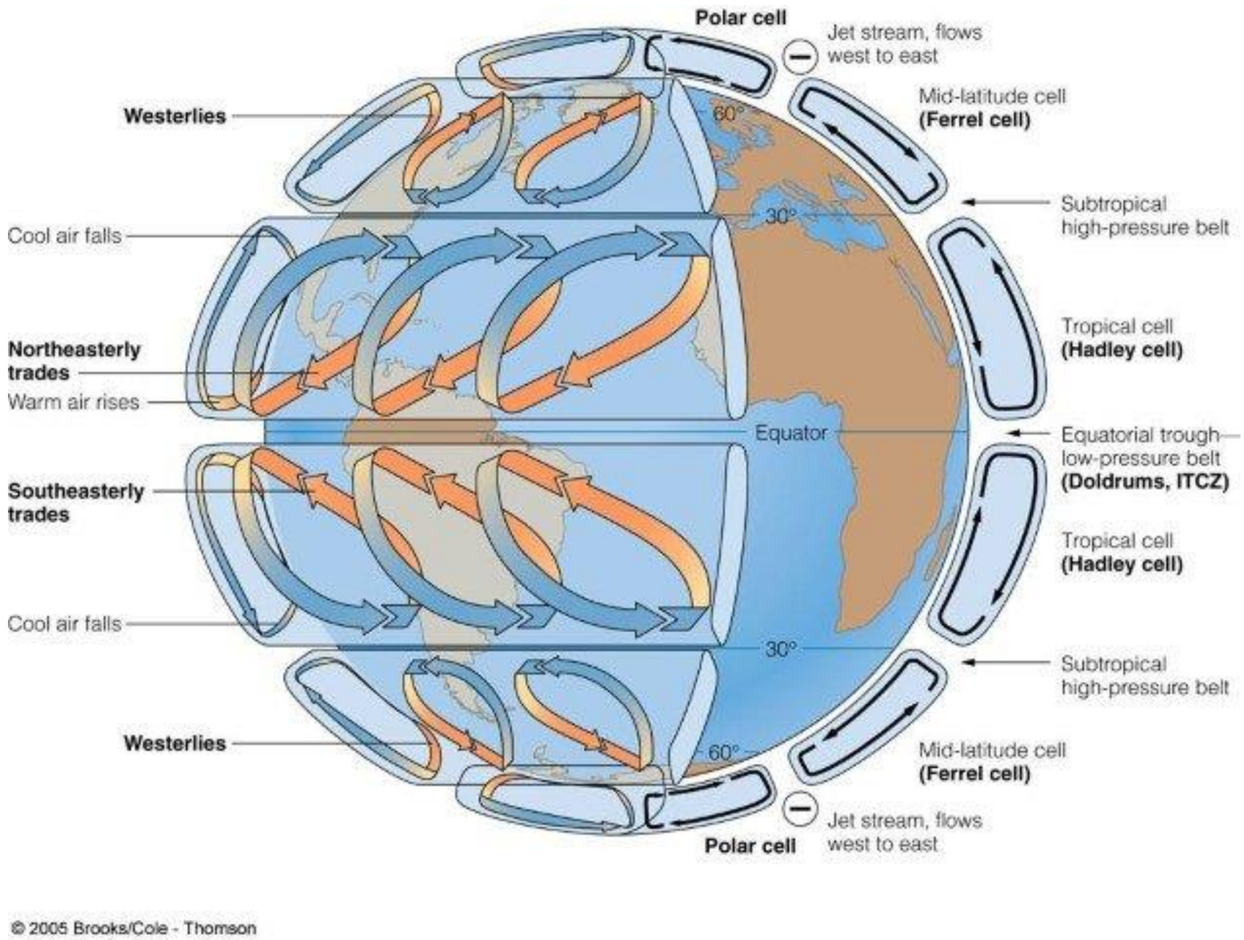
Polar cell
Jet stream, flows west to east
Westerlies
60°
Mid-latitude cell
(Ferrel cell)
Subtropical high-pressure belt
Cool air falls
30°
Tropical cell
(Hadley cell)
Northeasterly trades
Warm air rises
Equator
Equatorial trough—low-pressure belt
(Doldrums, ITCZ)
Southeasterly trades
Tropical cell
(Hadley cell)
Cool air falls
30°
Subtropical high-pressure belt
Westerlies
60°
Mid-latitude cell
(Ferrel cell)
Jet stream, flows west to east
Polar cell
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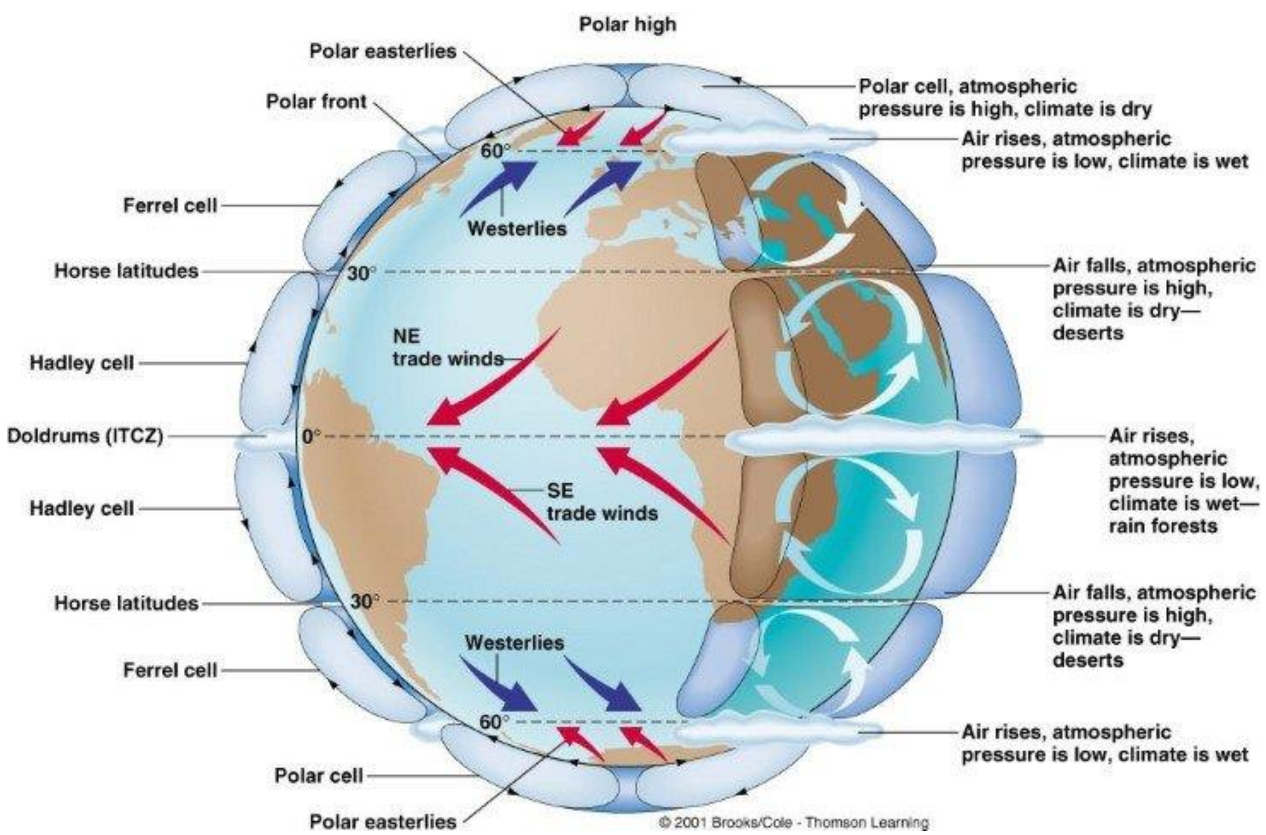
Polar high
Polar easterlies
Polar front
Polar cell, atmospheric pressure is high, climate is dry
Air rises, atmospheric pressure is low, climate is wet
60°
Ferrel cell
Westerlies
Horse latitudes
30°
Air falls, atmospheric pressure is high, climate is dry—deserts
NE trade winds
Hadley cell
Doldrums (ITCZ)
0°
Air rises, atmospheric pressure is low, climate is wet—rain forests
SE trade winds
Hadley cell
Horse latitudes
30°
Air falls, atmospheric pressure is high, climate is dry—deserts
Westerlies
Ferrel cell
60°
Air rises, atmospheric pressure is low, climate is wet
Polar cell
Polar easterlies
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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** etc..

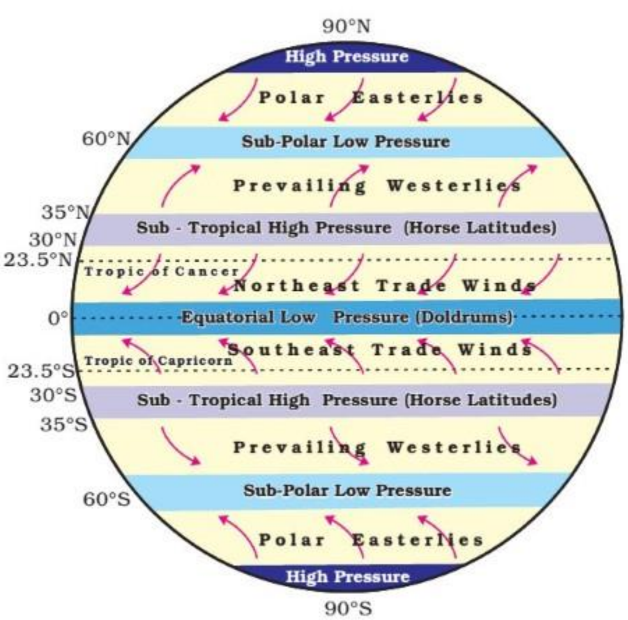
Local winds

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

Primary or Prevailing 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**.

The Trade Winds



Major Pressure Belts and Wind System

- 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.

The 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.

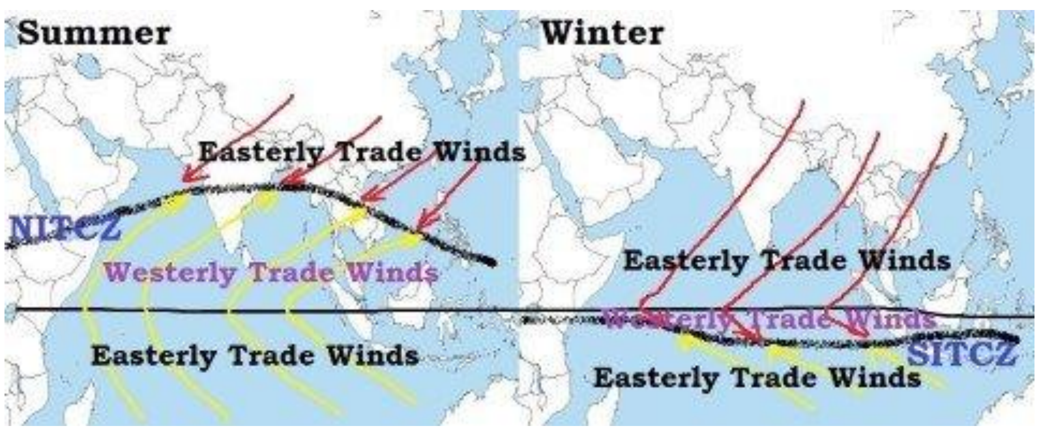
These winds produce **wet spells** and variability in weather.

The 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 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.**

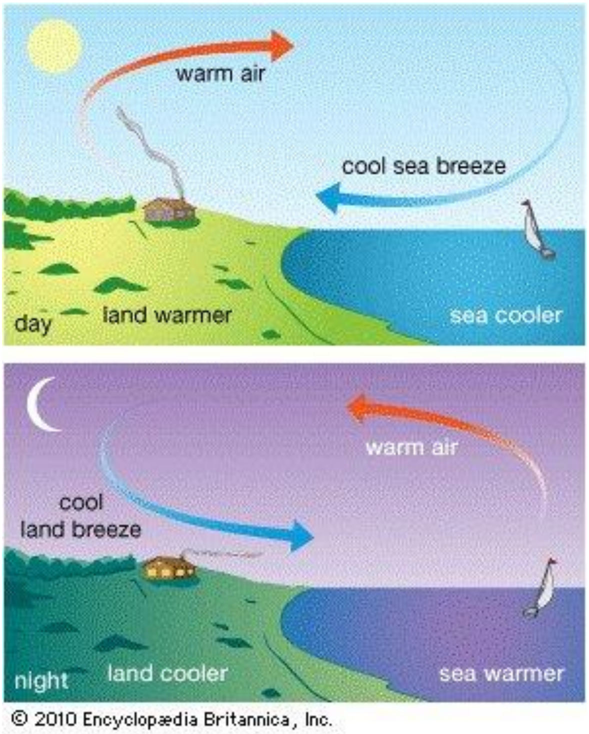


Monsoons

- 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 **Japan.**
- 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)

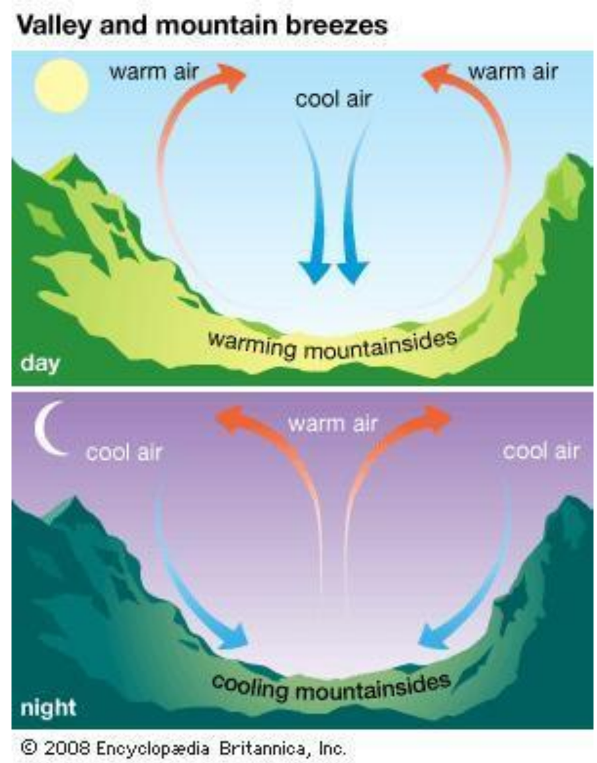
Land Breeze and Sea Breeze

- 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 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 **loo.** 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 **Chinooks.**
- 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.**

Cold wind	Warm winds
❑ Pampero	❑ Foehn or Fohn
❑ Gregale	❑ Chinook
❑ Bora	❑ Zonda
❑ Tramontane	❑ Loo
❑ Mistral	❑ Sirocco

Questions

Multiple choice questions

1. Multiple choice questions. (i) If the surface air pressure is 1,000 mb, the air pressure at 1 km above the surface will be: (a) 700 mb (c) 900 mb (b) 1,100 mb (d) 1,300 mb
2. The Inter Tropical Convergence Zone normally occurs: (a) near the Equator (b) near the Tropic of Cancer (c) near the Tropic of Capricorn (d) near the Arctic Circle
3. The direction of wind around a low pressure in northern hemisphere is: (a) clockwise (c) anti-clock wise (b) perpendicular to isobars (d) parallel to isobars
4. Which one of the following is the source region for the formation of air masses? (a) the Equatorial forest (c) the Siberian Plain (b) the Himalayas (d) the Deccan Plateau

30 words

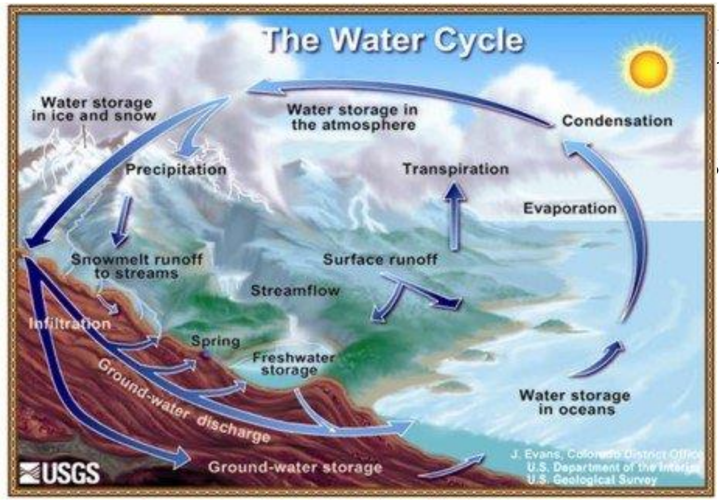
1. While the pressure gradient force is from north to south, i.e. from the subtropical high pressure to the equator in the northern hemisphere, why are the winds north easterlies in the tropics.
2. What are the geostrophic winds?
3. Explain the land and sea breezes.

150 words

- Discuss the factors affecting the speed and direction of wind.
- Draw a simplified diagram to show the general circulation of the atmosphere over the globe. What are the possible reasons for the formation of subtropical high pressure over 30° N and S latitudes?
- Why does tropical cyclone originate over the seas? In which part of the tropical cyclone do torrential rains and high velocity winds blow and why?

In this post: Atmospheric Moisture, Significance of Atmospheric Moisture; Humidity: Absolute Humidity, Relative Humidity, Dew point and Specific Humidity.

Water Cycle - Hydrological cycle



- There is a continuous exchange of water between the atmosphere, the oceans and the continents through the processes of **evaporation, transpiration, condensation and precipitation.**
- The moisture in the atmosphere is derived from water bodies through **evaporation** and from plants through **transpiration (evapotranspiration)**.
- Evaporated water undergoes **condensation** and forms clouds.
- When saturation is reached, clouds give away water in the form of **precipitation.**
- Since the total amount of moisture in the entire system remains constant, a balance is required between evapotranspiration and precipitation. The hydrological cycle maintains this balance.

Water Vapour in Atmosphere

- Water vapour in air varies from **zero to four per cent** by volume of the atmosphere (averaging around **2%** in the atmosphere). Amount of water vapour (Humidity) is measured by, an instrument called **hygrometer.**

Significance of Atmospheric Moisture

1. Water vapour absorbs radiation—**both incoming and terrestrial**. It thus plays a crucial role in the **earth's heat budget**.
2. The amount of water vapour present decides the **quantity of latent energy stored** up in the atmosphere for development of storms and cyclones.
3. The atmospheric moisture affects the human body's rate of cooling by influencing the sensible temperature.

Evaporation

- The oceans covering 71% of the earth's surface hold 97% of all the earth's water reserves.
- Evapotranspiration may be taken as the starting point in the hydrological cycle. The oceans contribute **84%** of the annual total and the continents **16%.**
- The highest annual evaporation occur in the **sub-tropics of the western North Atlantic** and **North Pacific** because of the influence of the **Gulf Stream** and the **Kurishino Current**, and in the **trade wind zone of the southern oceans**.
- The land maximum occurs in equatorial region because of **high insolation** and luxuriant **vegetation.**

Humidity

- Water vapour present in the air is known as **humidity.**

Absolute Humidity

- The **actual** amount of the water vapour present in the atmosphere is known as the **absolute humidity.**
- It is the **weight** of water vapour per unit volume of air and is expressed in terms of grams per cubic metre.
- The absolute humidity **differs** from place to place on the surface of the earth.
- The ability of the air to hold water vapour depends entirely on its **TEMPERATURE. Warm air can hold more moisture than cold air**.

Relative Humidity

- The **percentage of moisture present in the atmosphere as compared to its full capacity at a given temperature** is known as the relative humidity.
- **With the change of air temperature, the capacity to retain moisture increases or decreases and the relative humidity is also affected.**
- **It is greater over the oceans and least over the continents.**
- Relative humidity can be changed in either of the two ways—

1. **By adding moisture through evaporation**: if moisture is added by evaporation, the relative humidity will increase and vice versa.
2. **By changing temperature of air**: a decrease in temperature (hence, decrease in moisture-holding capacity) will cause a decrease in relative humidity and vice versa.

- The **relative humidity** determines the **amount and rate of evaporation** and hence it is an **important climatic factor.**
- Air containing moisture to its full capacity at a given temperature is said to be **'saturated'.** At this temperature, the air **cannot** hold any additional amount of moisture. Thus, relative humidity of the saturated air is **100%.**
- If the air has half the amount of moisture that it can carry, then it is unsaturated and its relative humidity is only **50%.**

Consider 1 m^3 of air at a temperature 'T'.

Let us assume that saturation occurs when 0.5 kg of water vapor is present in 1 m^3 of air

i.e. relative humidity will be 100% if 1 m^3 of atmosphere contains 0.5 kg of water vapor at temperature T.

Imagine that 1 m^3 of atmosphere at a given time is made up of 0.2 kg of water vapor at a temperature 'T'.

Now the relative humidity = 40 % ===> 0.2 kg of water vapor per 1 m^3 of atmosphere ===> the atmosphere can still hold 0.3 kg of water vapor since saturation occurs at 0.5 kg.

Here,

Absolute Humidity = 0.2 kg/ m³ and

Relative Humidity = 20 %

So, relative humidity is expressed as % whereas absolute humidity is expressed in absolute terms.

Now to make the air saturated (100 % relative humidity), we can add that additional 0.3 kg of water vapor by evaporation.

OR

We can decrease the temperature.

If we decrease the temperature, the saturation point will come down.

Let us image that the temperature of 1 m^3 of air is decreased by 2 °C. The water holding capacity will fall due to decrease in temperature. Let us say it decreases by 0.1 kg per 1 °C fall in temperature.

Now for 2 °C, the fall in water holding capacity is 0.1 kg x 2 = 0.2 kg.

Now the new saturation point = 0.5 kg – 0.2 kg = 0.3 kg.

Now "new saturation point (relative humidity = 100%)" occurs when the water vapor content is 0.3 kg for 1 kg of air.

Now we can saturate 1 m^3 of air by adding just 0.1 kg instead of 0.3 kg as in the earlier case.

Dew point

- The air containing moisture to its full capacity at a given temperature is said to be **saturated.**
- It means that the air at the given temperature is incapable of holding any additional amount of moisture at that stage.
- The temperature at which saturation occurs in a given sample of air is known as **dew point.**
- **Dew point occurs when Relative Humidity = 100%.**

Specific Humidity

- It is expressed as the **weight of water vapour per unit weight of air**.
- Since it is measured in units of weight (usually grams per kilogram), the specific humidity is **not affected by changes in pressure or temperature**.

Absolute Humidity and Relative Humidity are Variable whereas Specific Humidity is a constant.

In this post: Evaporation: Factors Affecting Rate of Evaporation; Condensation - Forms of Condensation: Dew, White Frost, Fog, Mist, Smog, Haze (similar to smog but there is no condensation in haze); Clouds: Cirrus clouds, Cumulus clouds, Stratus clouds, Nimbus clouds; High clouds – cirrus, cirrostratus, cirrocumulus; Middle clouds – altostratus and altocumulus; Low clouds – stratocumulus and nimbostratus and Clouds with extensive vertical development – cumulus and cumulonimbus.

Evaporation

- Evaporation is a process by which water is transformed from **liquid to gaseous state**. Heat is the main cause for evaporation.
- **Movement of air replaces the saturated layer with the unsaturated layer. Hence, the greater the movement of air, the greater is the evaporation**.

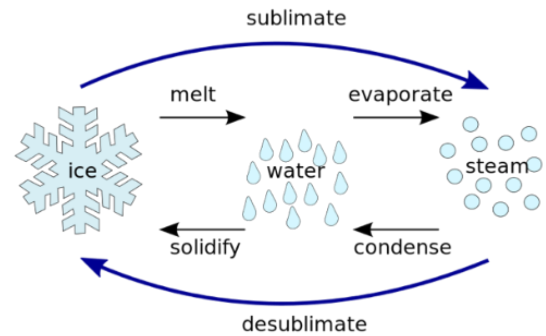
Factors Affecting Rate of Evaporation

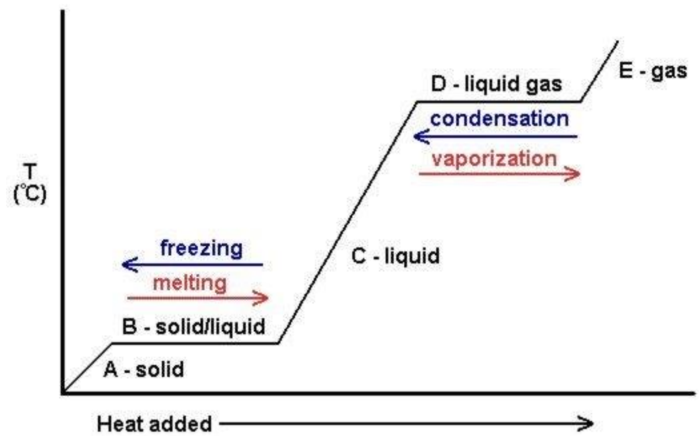
- **Amount of water available.**
- **Temperature.**
- **Relative humidity.** [explained in previous post]
- **Area of evaporating surface.**

- **Wind speed:** A high wind speed removes the saturated air from the evaporating surface and replaces it with dry air which favors more evaporation.
- Whenever there is a combination of **high temperature**, very **low relative humidity** and **strong winds**, the rate of evaporation is exceptionally high. This leads to **dehydration of soil** to a depth of several inches.
- **Air Pressure:** Evaporation is also affected by the atmospheric pressure exerted on the evaporating surface. Lower pressure over open surface of the liquid results in a higher rate of evaporation.
- **Composition of water:** Evaporation is **inversely proportional to salinity of water.**
- Rate of evaporation is always greater over fresh water than over salt water. [Because of the reduction in the water vapor pressure at the water surface due to salinity.]
- Under similar conditions, ocean water evaporates about 5% more slowly than fresh water.
- **More evaporation by plants:** Water from plants generally evaporates at a faster rate than from land.

Condensation

- The transformation of **water vapour into water** is called **condensation**.
- Condensation is caused by the **loss of heat (latent heat of condensation, opposite of latent heat of vaporization).**
- When moist air is cooled, it may reach a level when its capacity to hold water vapour ceases (Saturation Point = 100% Relative Humidity = Dew Point reached). Then, the excess water vapour condenses into liquid form. If it directly condenses into solid form, it is known as **sublimation.**
- In free air, condensation results from cooling around very small particles termed as **hygroscopic condensation nuclei**. Particles of **dust, smoke, pollen** and **salt** from the ocean are particularly good nuclei because they absorb water.





- Condensation also takes place when the moist air comes in contact with some colder object and it may also take place when the temperature is close to the **dew point.**
- Condensation, therefore, depends upon the **amount of cooling** and the **relative humidity** of the air.
- Condensation takes place:

1. when the temperature of the air is **reduced to dew point** with its volume remaining constant (**adiabatically**),
2. when both the volume and the temperature are reduced,
3. when moisture is added to the air through evaporation,

- After condensation the water vapour or the moisture in the atmosphere takes one of the following forms — **dew, frost, fog and clouds**.
- **Condensation takes place when the dew point is lower than the freezing point as well as higher than the freezing point.**

Processes of Cooling for Producing Condensation

- These processes can be studied under the" headings, **adiabatic and non-adiabatic.**

Adiabatic Temperature Changes

- (Explained in detail in previous posts)
- When the air rises, it expands. Thus, heat available per unit volume is reduced and, therefore, the temperature is also reduced. Such a temperature change which does not involve any subtraction of heat, and cooling of air takes place only by ascent and expansion, is termed 'adiabatic change'.
- The vertical displacement of the air is the major cause of **adiabatic and katabatic** (cold, dense air flowing down a slope) temperature changes.
- Near the earth's surface, most processes of change are **non-adiabatic** because horizontal movements often produce mixing of air and modify its characteristics.

Non-Adiabatic Temperature Changes

- Non-adiabatic processes include cooling by **radiation, conduction or mixing** with colder air. The air may be cooled due to loss of heat by radiation.
- In case there is direct radiation from moist air, the cooling produces **fog or clouds**, subject to presence of hygroscopic nuclei in the air.
- Cooling by contact with a cold surface produces **dew, frost or fog** depending on other atmospheric conditions.
- But the effect of cooling produced by radiation, conduction and mixing is confined to a thin layer of the atmosphere.
- The non-adiabatic processes of cooling produce only dew, fog or frost. They are **incapable** of producing a substantial amount of precipitation.

Forms of Condensation

- The forms of condensation can be classified on the basis of temperature at which the dew point is reached.
- Condensation can take place when the dew point is

1. **lower than the freezing point,**
2. **higher than the freezing point.**

- **White frost, snow and some clouds (cirrus clouds)** are produced when the temperature is lower than the freezing point.
- **Dew, fog and clouds** result even when the temperature is higher than the freezing point.
- Forms of condensation may also be classified on the basis of their location, i.e. at or near the earth's surface and in free air.
- **Dew, white frost, fog and mist** come in the first category, whereas **clouds** are in the second category.

Dew

- When the moisture is deposited in the form of water droplets on cooler surfaces of solid objects (rather than nuclei in air above the surface) such as stones, grass blades and plant leaves, it is known as dew.
- The ideal conditions for its formation are **clear sky, calm air, high relative humidity**, and **cold and long nights**.
- For the formation of dew, it is necessary that the **dew point is above the freezing point.**

White Frost

- Frost forms on cold surfaces when condensation takes place **below freezing point (0° C)**, i.e. the **dew point** is at or below the freezing point.
- The excess moisture is deposited in the form of **minute ice crystals** instead of water droplets.
- The ideal conditions for the formation of white frost are the same as those for the formation of dew, except that the **air temperature must be at or below the freezing point.**

Fog

- When the temperature of an air mass containing a large quantity of water vapour falls all of a sudden, condensation takes place within itself on fine dust particles.
- So, the fog is a **cloud with its base at or very near to the ground**. Because of the **fog and mist**, the visibility becomes poor to zero.
- In urban and industrial centers smoke provides plenty of nuclei which help the formation of fog and mist. Such a condition when fog is mixed with smoke, is described as **smog (will be discussed in detail in next post).** [Related Question Asked in Mains 2015: ***Mumbai, Delhi and Kolkata are the three mega cities of the country but the air pollution is much more serious problem in Delhi as compared to the other two. Why is this so?]***
- **Radiation fog** results from radiation, cooling of the ground and adjacent air. These fogs are **not very thick**. Usual in winters.
- Fogs formed by condensation of warm air when it moves horizontally over a cold surface, are known as **advectional fog**. These fogs are **thick and persistent**. Occurs over warm and cold water mixing zones in oceans.
- **Frontal or precipitation fog** is produced due to convergence of warm and cold air masses where warm air mass is pushed under by the heavier cold air mass.
- Precipitation in the warm air mass condenses to produce fog at the boundary of the two air masses. These are called **frontal or precipitation fog**.
- **In fog visibility is less than one kilometer**.

Mist

- The difference between the mist and fog is that mist contains more moisture than fog.
- In mist each nuclei contains a thicker layer of moisture.
- Mists are frequent over mountains as the rising warm air up the slopes meets a cold surface.
- Mist is also formed by water droplets, but with less merging or coalescing. This means mist is less dense and quicker to dissipate.
- Fogs are drier than mist and they are prevalent where warm currents of air come in contact with cold currents.
- **In mist visibility is more than one kilometer but less than two kilometres.**

Haze

- Haze is traditionally an atmospheric phenomenon where dust, smoke and other dry particles obscure the clarity of the sky (No condensation. Smog is similar to haze but there is condensation in smog).
- Sources for haze particles include farming (ploughing in dry weather), traffic, industry, and wildfires.

Smog

- Smog = smoke + fog (smoky fog) caused by the burning of large amounts of coal, vehicular emission and industrial fumes (Primary pollutants).

We will study about smog in detail in the next post.

Clouds

- Cloud is a mass of minute water droplets or tiny crystals of ice formed by the condensation of the water vapour in free air at considerable elevations.
- Clouds are caused mainly by the **adiabatic cooling of air below its dew point.**
- As the clouds are formed at some height over the surface of the earth, they take various shapes.
- According to their height, expanse, density and transparency or opaqueness clouds are grouped under four types **: (i) cirrus; (ii) cumulus; (iii) stratus; (iv) nimbus.**

Cirrus Clouds

- Cirrus clouds are formed at high altitudes (8,000 - 12,000m). They are thin and detached clouds having a feathery appearance. They are always white in colour.

Cumulus Clouds

- Cumulus clouds look like cotton wool. They are generally formed at a height of 4,000 -7,000 m. They exist in patches and can be seen scattered here and there. They have a flat base.

Stratus Clouds

- As their name implies, these are layered clouds covering large portions of the sky.
- These clouds are generally formed either due to loss of heat or the mixing of air masses with different temperatures.

Nimbus Clouds

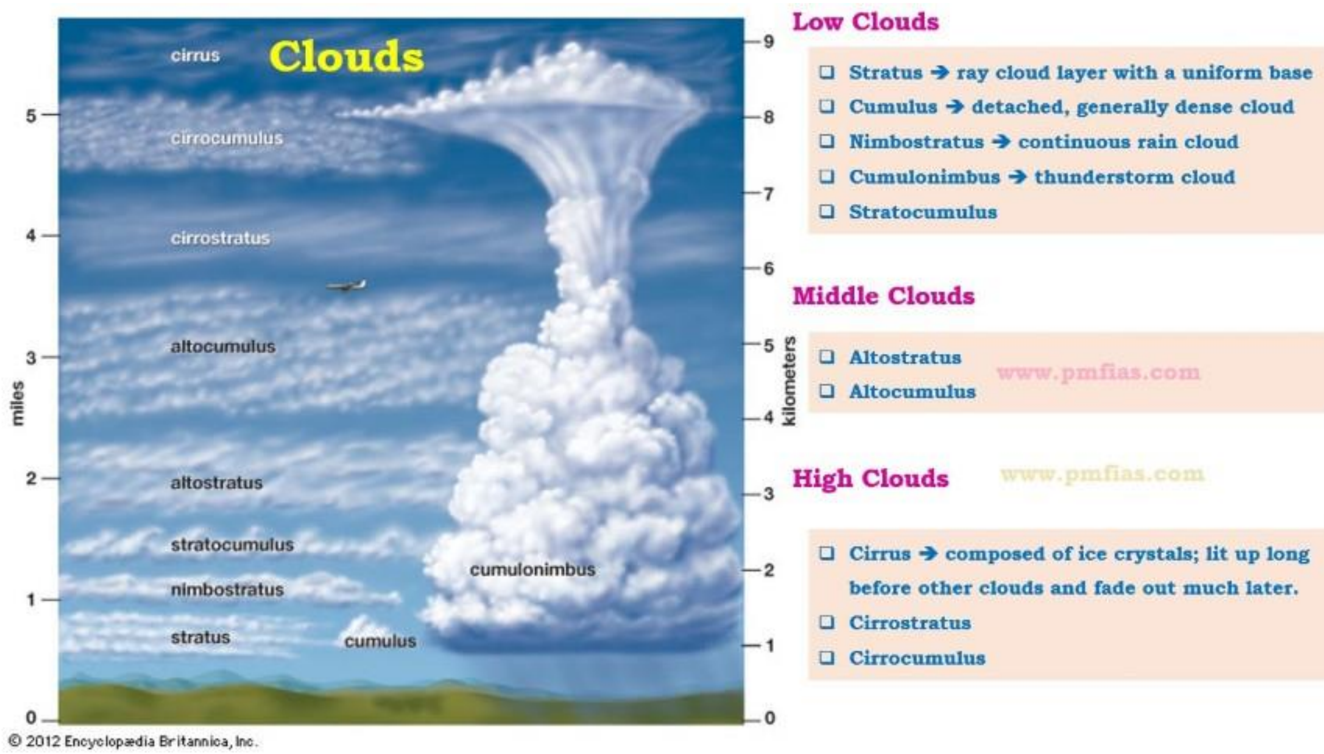
- Nimbus clouds are black or dark gray. They form at middle levels or very near to the surface of the earth.
- These are extremely dense and opaque to the rays of the sun.
- Sometimes, the clouds are so low that they seem to touch the ground.
- Nimbus clouds are shapeless masses of thick vapour.

A combination of these four basic types can give rise to the following types of clouds:

1. **High clouds – cirrus, cirrostratus, cirrocumulus;**
2. **Middle clouds – altostratus and altocumulus;**

3. **Low clouds – stratocumulus and nimbostratus (long duration rainfall cloud) and**
4. **Clouds with extensive vertical development – cumulus and cumulonimbus (thunderstorm cloud)**

Sun's halo is produced by the refraction of light in: [2002]
(a) water vapour in Stratus clouds
(b) ice crystals in Cirro-Cumulus clouds
(c) **ice crystals in Cirrus clouds**
(d) dust particles in Stratus clouds



In this Post: Smog - Primary and secondary pollutants; Types of Smog: Sulfurous smog [London Smog] and Photochemical smog [Los Angeles Smog]; Effects of Smog; Question UPSC Mains 2015: Mumbai, Delhi and Kolkata are the three mega cities of the country but the air pollution is much more serious problem in Delhi as compared to the other two. Why is this so?] [200 words]

Smog

- Smog = **smoke + fog (smoky fog)** caused by the burning of large amounts of **coal, vehicular emission** and **industrial fumes** (Primary pollutants).
- Smog contains soot particulates like **smoke, sulphur dioxide, nitrogen dioxide** and other components.
- At least two distinct types of smog are recognized: **sulfurous smog** and **photochemical smog**.

Primary and secondary pollutants

- A primary pollutant is an air pollutant emitted directly from a source.
- A secondary pollutant is not directly emitted as such, but forms when other pollutants (primary pollutants) react in the atmosphere.
- Examples of a secondary pollutant include **ozone**, which is formed when

1. hydrocarbons (HC) and nitrogen oxides (NOx) combine in the presence of sunlight;
2. NO combines with oxygen in the air; and
3. acid rain, which is formed when sulfur dioxide or nitrogen oxides react with water.

Sulfurous smog

- Sulfurous smog is also called **"London smog,"** (first formed in London).
- Sulfurous smog results from a high concentration of **SULFUR OXIDES** in the air and is caused by the use of **sulfur-bearing fossil fuels, particularly coal** (Coal was the mains source of power in London during nineteenth century. The effects of coal burning were observed in early twentieth century).
- This type of smog is aggravated by **dampness** and a **high concentration of suspended particulate matter** in the air.

Photochemical smog

- Photochemical smog is also known as **"Los Angeles smog".**
- Photochemical smog occurs most prominently in urban areas that have large numbers of automobiles (**Nitrogen oxides** are the primary emissions).
- Photochemical **(summer smog)** forms when pollutants such as **nitrogen oxides** (primary pollutant) and **organic compounds** (primary pollutants) react together in the presence of **SUNLIGHT**. A gas called **OZONE** (Secondary pollutant) is formed.

Nitrogen Dioxide + Sunlight + Hydrocarbons = Ozone (Ozone in stratosphere it is beneficial, but near the earth's surface it results in global warming as it is a greenhouse gas)

- The resulting smog causes a light brownish coloration of the atmosphere, reduced visibility, plant damage, irritation of the eyes, and respiratory distress.

Reactions involved

Atmospheric oxidant production:

1. $NO + VOC \rightarrow NO_2$ (nitrogen dioxide)
2. $NO_2 + UV \rightarrow NO + O$ (nitric oxide + atomic oxygen)
3. $O + O_2 \rightarrow O_3$ (ozone)
4. $NO_2 + VOC \rightarrow$ PAN, etc. (peroxyacetyl nitrate)

Net results:

$NO + VOC + O_2 + UV \rightarrow O_3$, PAN, and other oxidants

Haze

- Haze is traditionally an atmospheric phenomenon where dust, smoke and other dry particles obscure the clarity of the sky (No condensation. Smog is similar to haze but there is condensation in smog).
- Sources for haze particles include farming (ploughing in dry weather), traffic, industry, and wildfires.

Effects of Smog

- The **atmospheric pollution** levels of Los Angeles, Beijing, Delhi, Mexico City and other cities are increased by **inversion** that traps pollution close to the ground.
- It is usually highly toxic to humans and can cause severe sickness, shortened life or death.
- Smog is a combination of airborne particulate matter, like soot, and invisible toxic gases including **ozone (O3), carbon monoxide (CO), sulfur dioxide (SO2)**, which are **carcinogens (cancer causing agents).**
- Temperature inversions are accentuated and **precipitation is reduced**.
- Smog related Haze lowers visibility.

Toxic Chemical	Sources	Environmental Effects
Nitrogen Oxides (NO and NO2)	❑ combustion of oil, coal, gas ❑ bacterial action in soil ❑ forest fires, volcanic action ❑ lightning	❑ decreased visibility due to yellowish color of NO2 ❑ NO2 can suppress plantgrowth
Volatile Organic Compounds (VOCs)	❑ evaporation of fuels ❑ incomplete combustion of fossil fuels	❑ eye irritation ❑ respiratory irritation ❑ some are carcinogenic ❑ decreased visibility due to blue-brown haze
Ozone (O3)	❑ formed from photolysis of NO2 ❑ sometimes results from stratospheric ozone intrusions	❑ decreased crop yields ❑ retards plant growth ❑ damages plastics ❑ breaks down rubber
Peroxyacetyl Nitrates (PAN)	❑ formed by the reaction of NO2with VOCs	❑ eye irritation ❑ high toxicity to plants ❑ damaging to proteins

Question UPSC Mains 2015

Mumbai, Delhi and Kolkata are the three mega cities of the country but the air pollution is much more serious

problem in Delhi as compared to the other two. Why is this so?] [200 words]

- In spite of similar urbanization, air pollution is much more severe in Delhi compared to that in Mumbai and Kolkata. This is because of

Polluting Industry in close vicinity in Delhi.

- Delhi and its immediate neighborhood is the hot bed of polluting industries which are primarily coal fueled. Burning coal releases Oxides of sulphur which forms sulphurous smog. This type of smog is more pronounced in Delhi than in the other two cities due to geography and climate.

Vehicular Emissions

- All the three cities contribute nearly equal vehicular emissions rich in CO2 and NO2. NO2 results in phochemical smog. Here again, Delhi is worst hit due to its geography and climate.

Geography and Climate

- This the **most detrimental factor**. Delhi is a **continental city** while the other two are coastal. Land and See Breezes in Mumbai and Kolkata carry pollutants away from the city. There is no such advantage to Delhi as it is land locked.
- Also, the **duration of monsoon winds** is short in Delhi compared to the other two.
- Delhi faces severe cold wave in winter compared to the other two. Cold climate here creates temperature inversion which traps the pollutants, mainly smog, for a longer duration.

Farm Straw Burning

- Delhi is at the heart of major agricultural region. Burning of farm straw in the surrounding regions also adds to Delhi's pollution levels.

226 words. Cutting those 26 words will be detrimental for success.

In this post: Precipitation; Types of Rainfall: Conventional Rainfall, Orographic Rainfall, Frontal Precipitation, Cyclonic Rain and Monsoonal Rainfall; World Distribution of Rainfall.

Precipitation

- The process of continuous condensation in free air helps the condensed particles to grow in size. When the resistance of the air fails to hold them against the force of gravity, they fall on to the earth's surface. So after the condensation of water vapour, the release of moisture is known as precipitation. This may take place in liquid or solid form.
- Precipitation in the form of drops of water is called rainfall, when the drop size is more than **0.5 mm**.
- It is called **virage** when raindrops evaporate before reaching the earth while passing through dry air.
- **Drizzle** is light rainfall with drop size being less than 0.5 mm, and when evaporation occurs before reaching the ground, it is referred to as **mist.**
- When the temperature is lower than the 0° C, precipitation takes place in the form of fine flakes of snow and is called **snowfall**. Moisture is released in the form of hexagonal crystals. These crystals form flakes of snow. Besides rain and snow, other forms of precipitation are **sleet** and **hail** (more about hail while studying thunderstorms), though the latter are limited in occurrence and are sporadic in both time and space.
- **Sleet** is frozen raindrops and refrozen melted snow-water. When a layer of air with the temperature above freezing point overlies a subfreezing layer near the ground, precipitation takes place in the form of sleet.
- Raindrops, which leave the warmer air, encounter the colder air below. As a result, they solidify and reach the ground as small pellets of ice not bigger than the raindrops from which they are formed. Sometimes, drops of rain after being released by the clouds become solidified

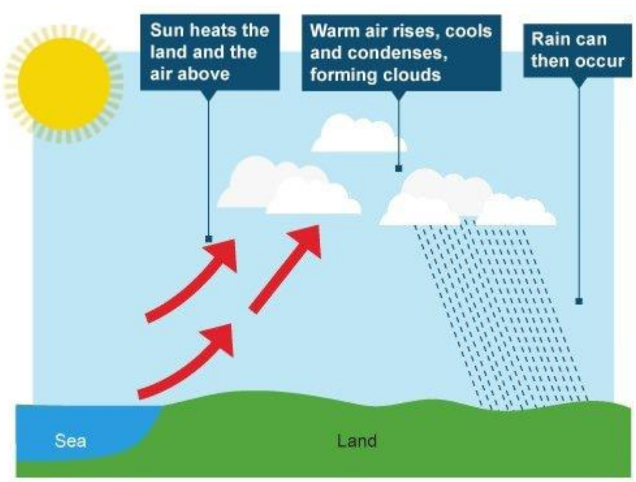
into small rounded solid pieces of ice and which reach the surface of the earth are called **hailstones**. These are formed by the rainwater passing through the colder layers. Hailstones have several **concentric** layers of ice one over the other.

- **Rainfall:** drop size more than 0.5 mm
- **Virage:** raindrops evaporate before reaching the earth
- **Drizzle:** light rainfall; drop size less than 0.5 mm
- **Mist:** evaporation occurs before reaching the ground leading to foggy weather
- **Snowfall:** fine flakes of snow fall when the temperature is less than 0°C
- **Sleet:** frozen raindrops and refrozen melted snow; mixture of snow and rain or merely partially melted snow
- **Hail:** precipitation in the form of hard rounded pellets is known as hail; 5 mm and 50 mm

Types of Rainfall

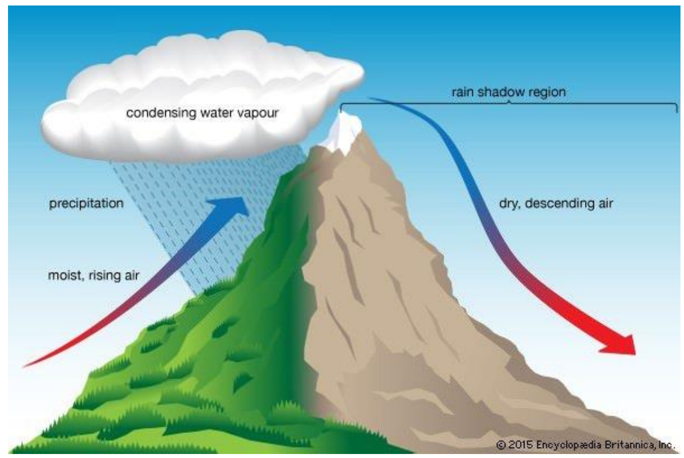
- On the basis of origin, rainfall may be classified into three main types – the **convectional, orographic or relief** and the **cyclonic or frontal.**

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 doldrums** in the Congo basin, the Amazon basin and the islands of south-east Asia.

Orographic Rainfall



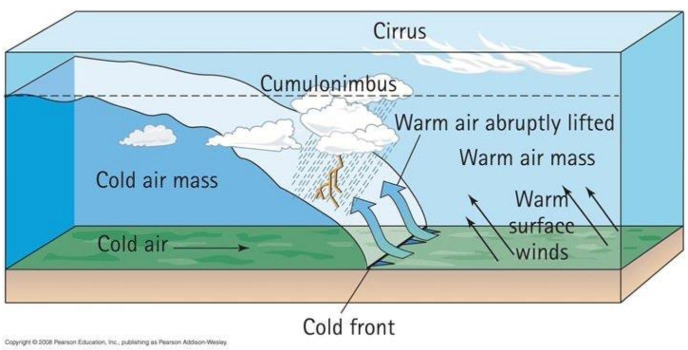
- When the saturated air mass comes across a mountain, it is forced to ascend and as it rises, it expands (because of fall in pressure); the temperature falls, and the moisture is condensed.
- This type of precipitation occurs when warm, humid air strikes an orographic barrier (a mountain range) head 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.

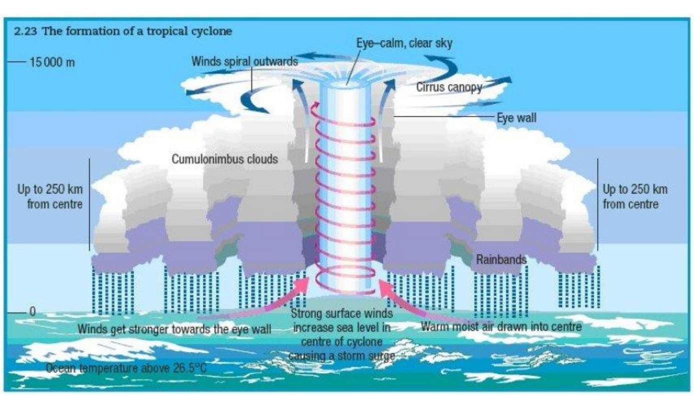
Frontal Precipitation

- 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.



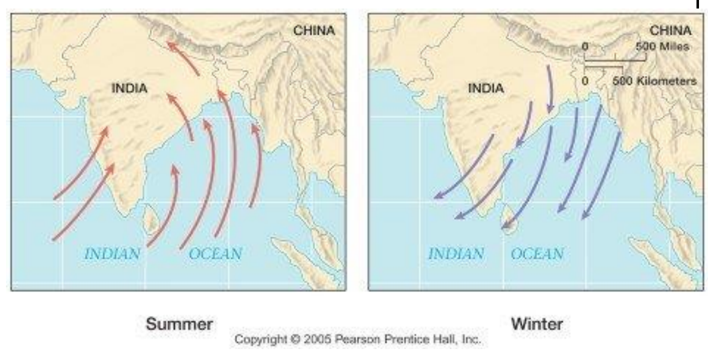
Cyclonic Rain

- 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).

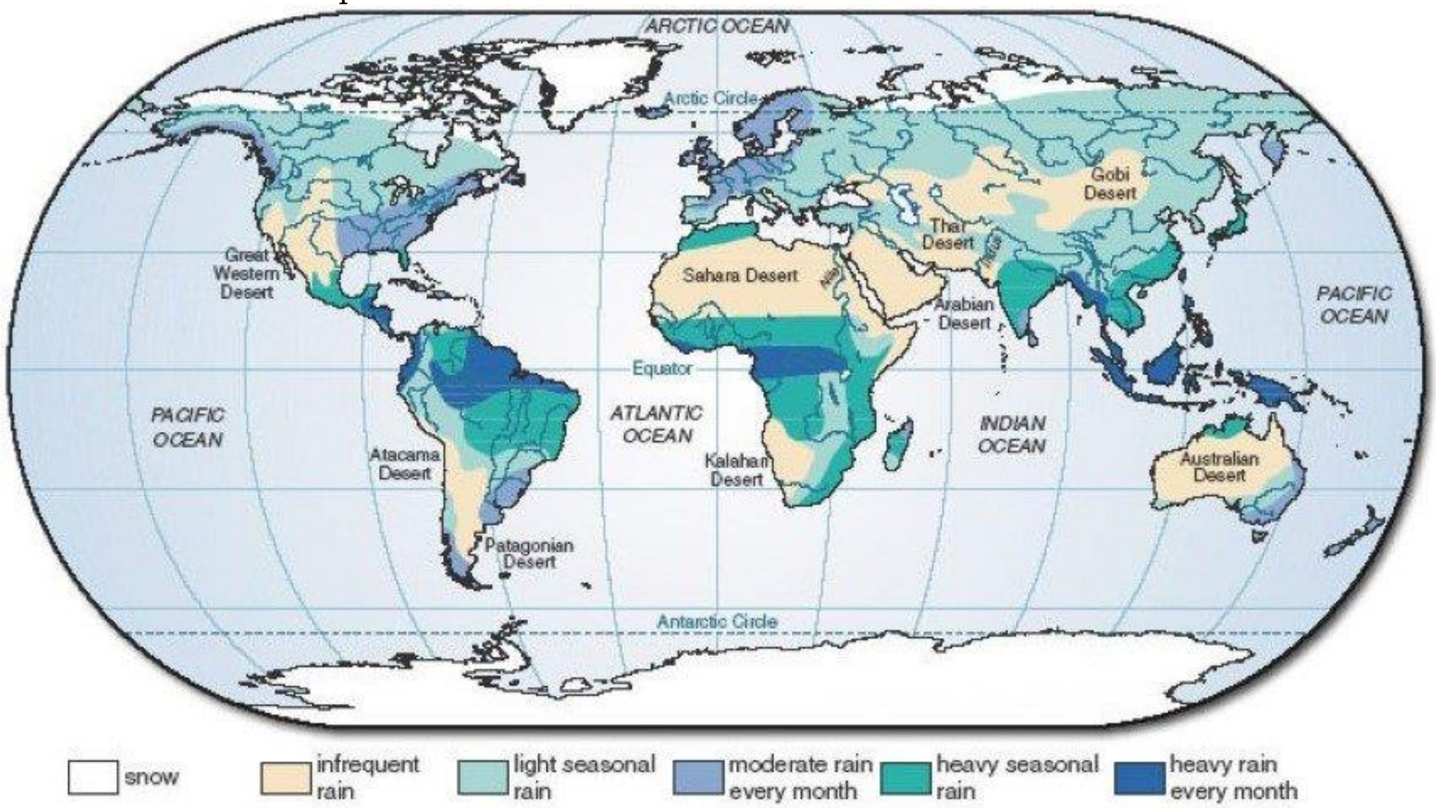


World Distribution of Rainfall

- 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.



Questions

Multiple choice questions

1. Which one of the following process is responsible for transforming liquid into vapour? (a) Condensation (c) Evaporation (b) Transpiration (d) Precipitation
2. The air that contains moisture to its full capacity : (a) Relative humidity (c) Absolute humidity (b) Specific humidity (d) Saturated air
3. Which one of the following is the highest cloud in the sky? (a) Cirrus (c) Nimbus (b) Stratus (d) Cumulus

30 words

- Name the three types of precipitation.
- Explain relative humidity.
- Why does the amount of water vapour decreases rapidly with altitude?
- How are clouds formed? Classify them

150 words

- Discuss the salient features of the world distribution of precipitation.
- What are forms of condensation? Describe the process of dew and frost formation.

In this post: Thunderstorm, Types of Thunderstorms, Lightning and Thunder, Tornado and Waterspout.

Thunderstorm

- Thunderstorms and tornadoes are **severe local storms**. They are of **short duration**, occurring over a **small area** but are **violent**.
- Thunderstorm is a storm with **thunder and lightning** and typically also **heavy rain or hail.**
- Thunderstorms **mostly occur on ground** where the temperature is high. Thunderstorms are less frequent on water bodies due to low temperature.
- Worldwide, there are an estimated 16 million thunderstorms each year, and at any given moment, there are roughly 2,000 thunderstorms in progress.

How does a thunderstorm form?

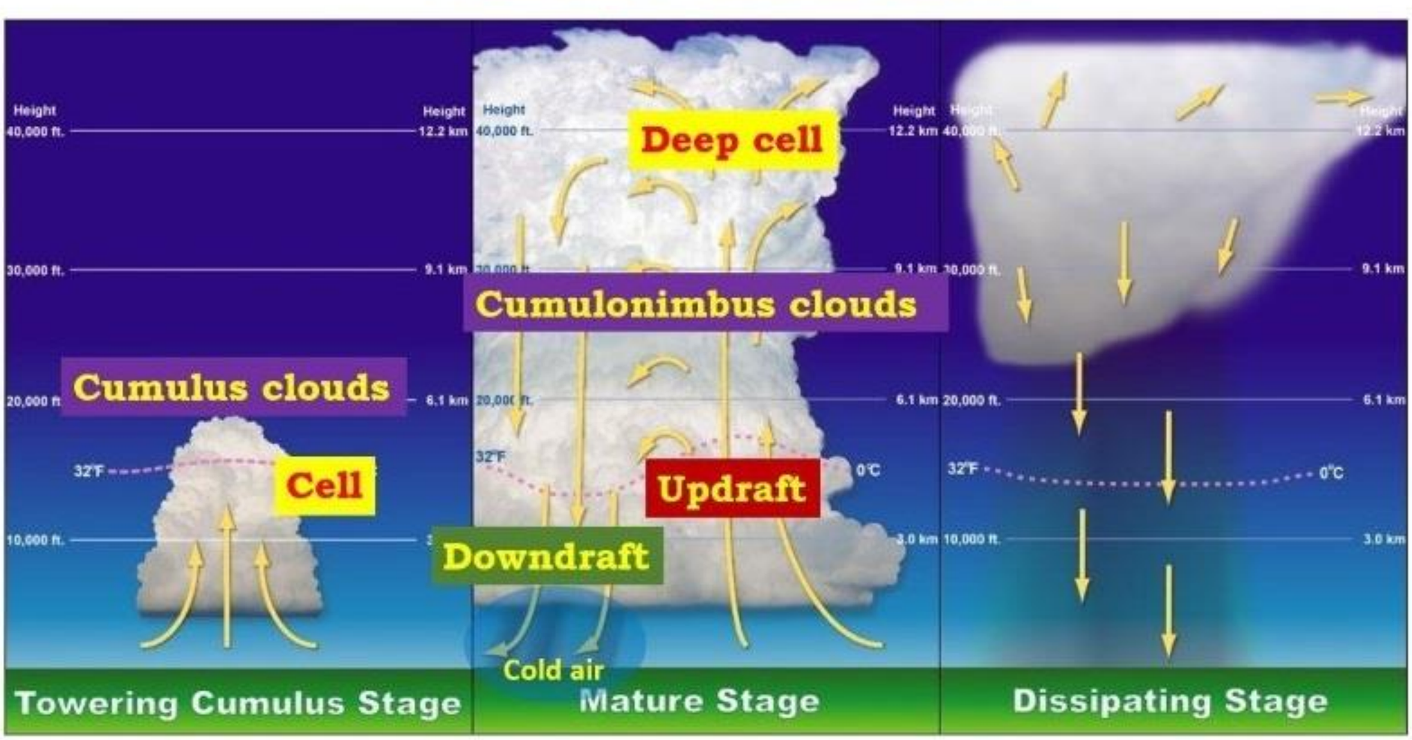
Cumulus stage

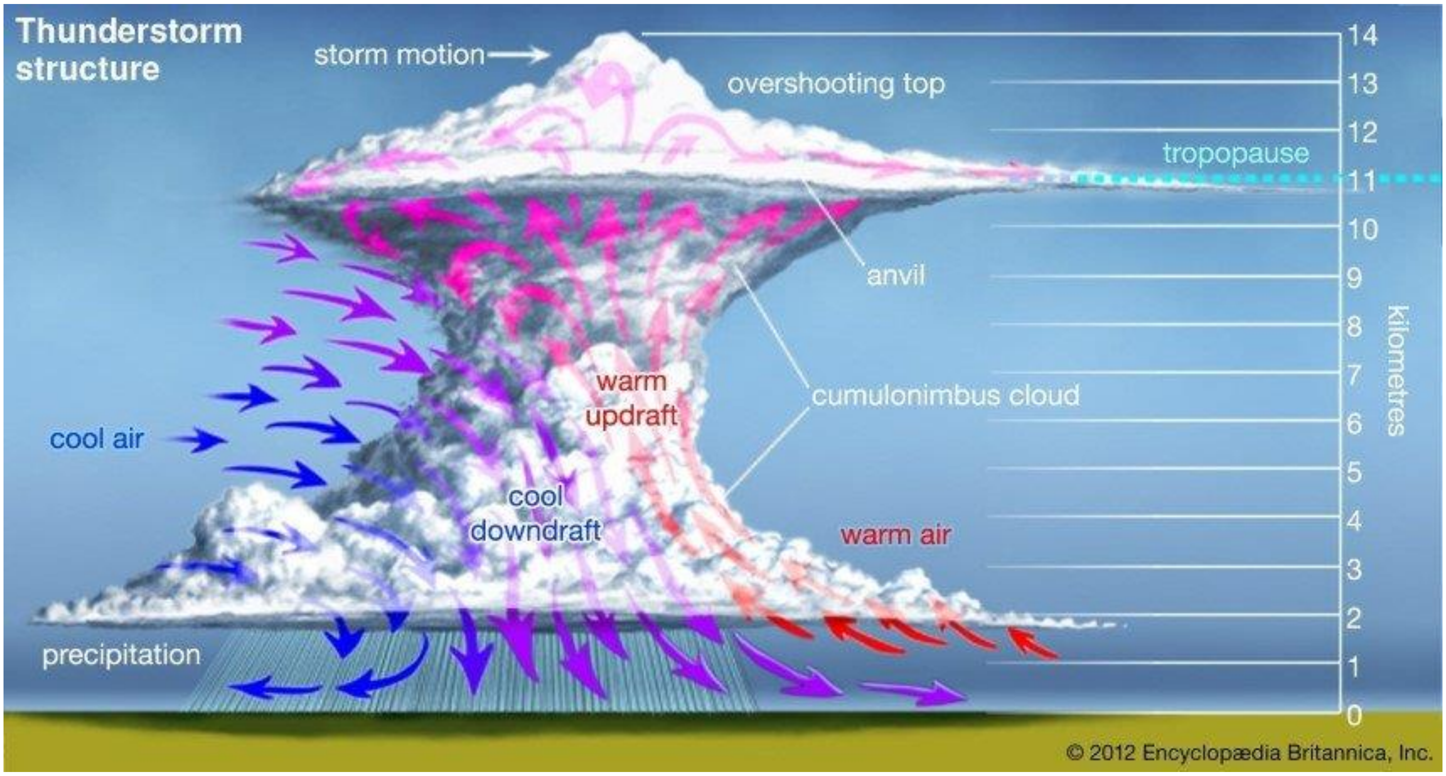
- Ground is significantly heated due to solar insolation.
- A low pressure starts to establish due to intense upliftment of an air parcel (convention).
- Air from the surroundings start to rush in to fill the low pressure.
- Intense convection of moist hot air builds up a towering cumulonimbus cloud. [I have explained how condensation occurs in previous post]

Mature stage

- Characterized by intense updraft of rising warm air, which causes the clouds to grow bigger and rise to greater height.
- Later, downdraft brings down to earth the cool air and rain.
- The incoming of thunderstorm is indicated by violent gust of wind. This wind is due to the intense downdraft.
- The updraft and downdraft determine the path of the thunderstorm. Most of the time, the path is erratic.

Formation of Thunderstorms





Dissipating stage

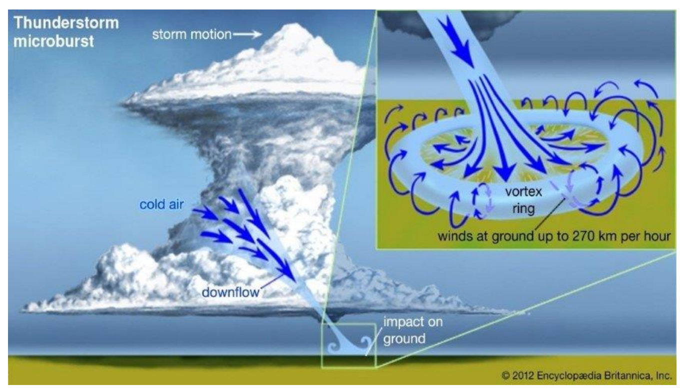
- When the clouds extend to heights where sub-zero temperature prevails, hails are formed and they come down as hailstorm. Intense precipitation occurs.
- In a matter of few minutes, the storm dissipates and clear weather starts to prevail.

Motion of a thunderstorm

- Path of a thunderstorm is erratic. Motion is primarily due to **interactions of its updrafts and downdrafts.**
- The speed of isolated storms is typically about 20 km (12 miles) per hour, but some storms move much faster.
- In extreme circumstances, a supercell storm may move 65 to 80 km (about 40 to 50 miles) per hour.

Downbursts

- Downdrafts are referred to as macrobursts or microbursts.
- Macroburst is more than 4 km in diameter and can produce winds as high as 60 metres per second, or 215 km per hour.
- A microburst is smaller in dimension but produces winds as high as 75 metres per second, or 270 km per hour
- They are **seriously hazardous to aircrafts**, especially during takeoffs and landings.

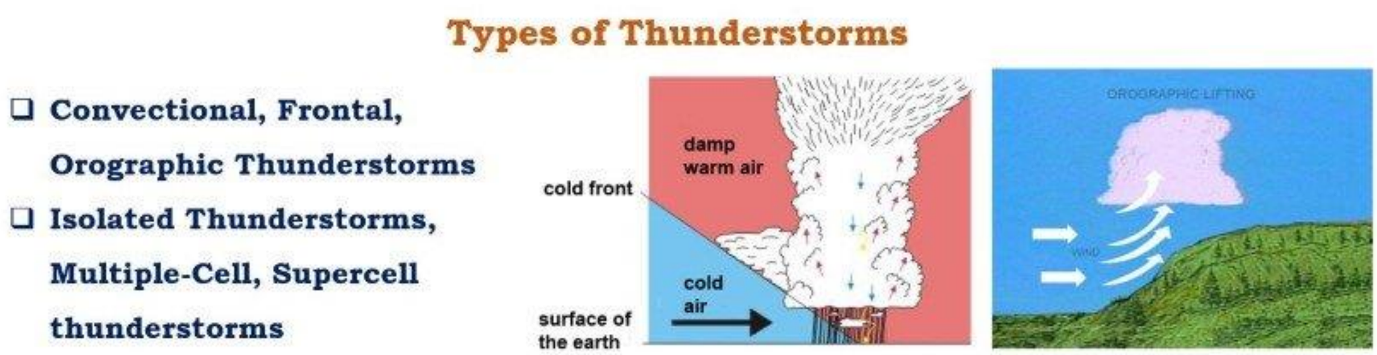


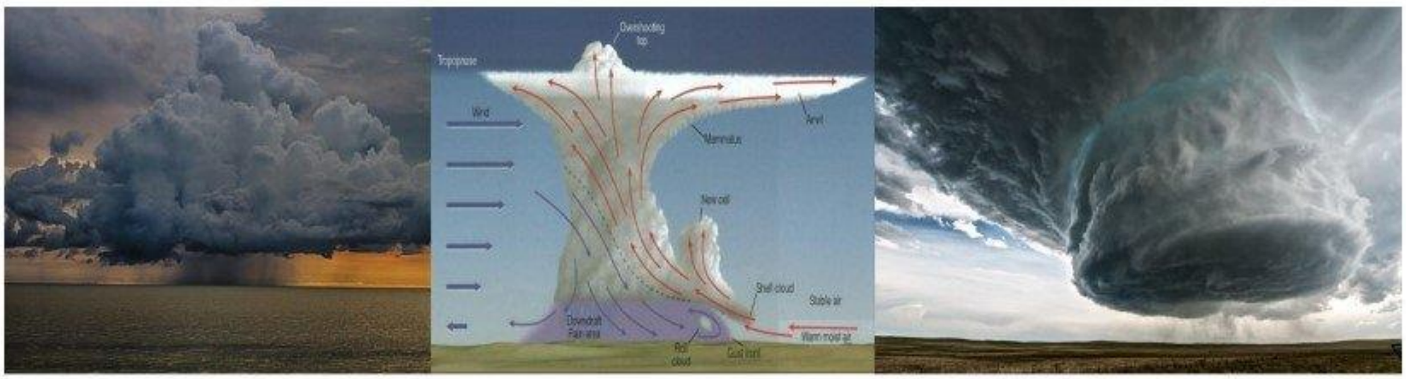
Types of Thunderstorms

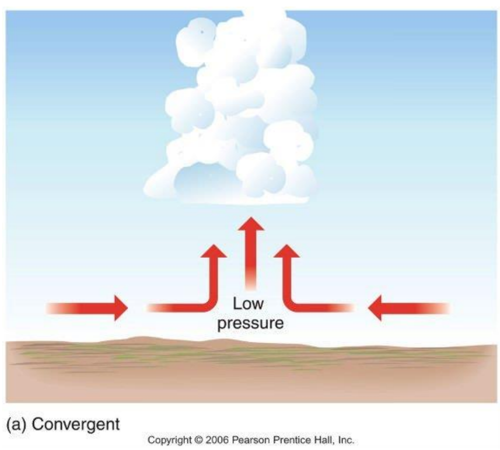
- Convectional, Frontal, Orographic Thunderstorms.
- Isolated Thunderstorms, Multiple-Cell Thunderstorms, Supercell thunderstorms.

Thermal thunderstorm

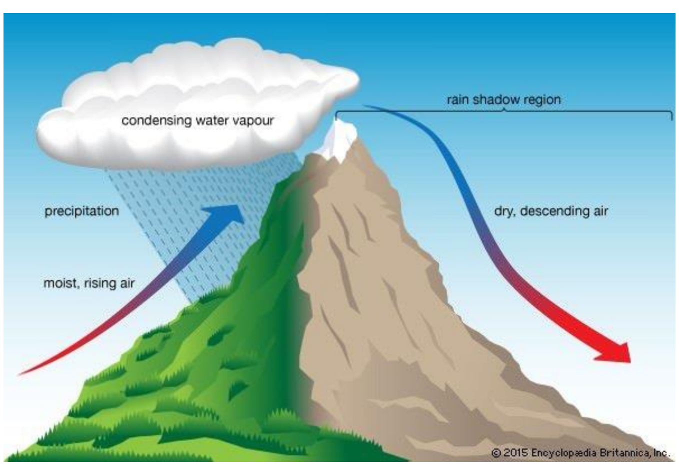
- Caused due to intense heating of ground during summer.





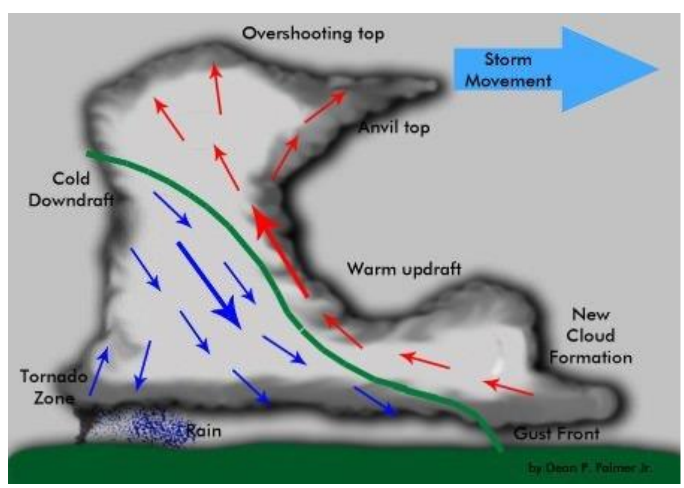


Orographic thunderstorm



- Forceful upliftment of warm moist air parcel when it passes over a mountain barrier creates cumulonimbus cloud causing heavy precipitation on the windward side.
- **Orographic 'Cloud bursts' are common in Jammu and Kashmir, Cherrapunji and Mawsynram.**

Frontal thunderstorm



- Thunderstorms occurring along cold fronts.

Single-cell thunderstorm

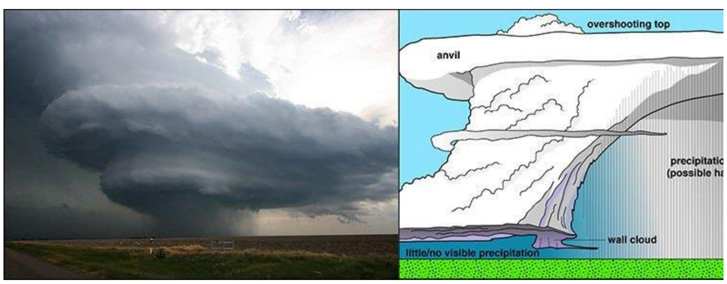
- Single-cell thunderstorms are small, brief, weak storms that grow and die within an hour or so. They are typically driven by heating on a summer afternoon.
- Single-cell storms may produce brief heavy rain and lightning (Very common in India during summers, mostly April, May. In **Kerala** they are called **'Mango Showers'** and in Karnataka **'Blossom showers'**).

A multi-cell thunderstorm

- A multi-cell storm is a thunderstorm in which new updrafts form along the leading edge of rain-cooled air (the gust front).
- Individual cells usually last 30 to 60 minutes, while the system as a whole may last for many hours.
- Multicell storms may produce hail, strong winds, brief tornadoes, and/or flooding.

A supercell thunderstorm

- A supercell is a long-lived (greater than 1 hour) and highly organized storm feeding off an updraft (a rising current of air) that is tilted and rotating.
- Most large and violent tornadoes come from supercells.



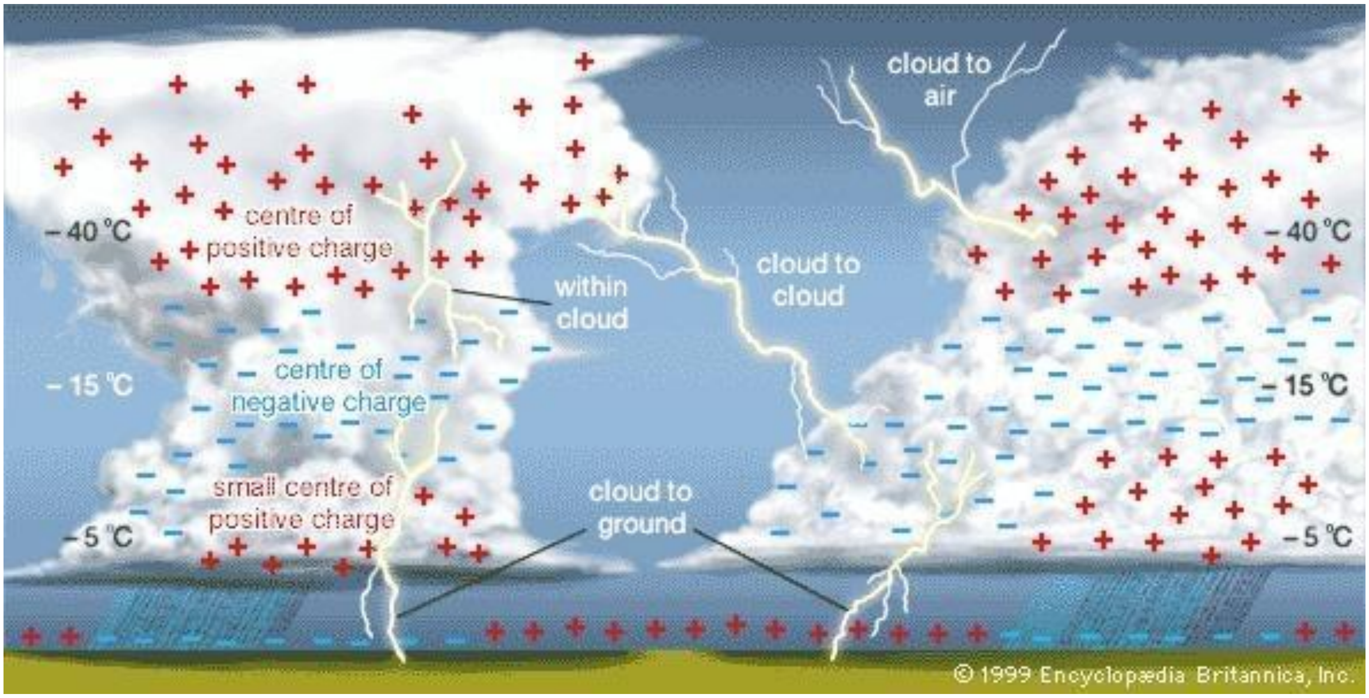
Lightning and thunder

- As water vapour moves upward in the cumulonimbus cloud, decreasing temperatures causes it to condense.
- The heat (latent heat of condensation) generated in the process pushes the water molecules further up.
- As they move beyond zero degrees, water droplets change into small ice crystals.
- As they continue to move up, they gather mass — until they are so heavy that they start to fall.
- This leads to a system where smaller ice crystals move up while bigger crystals come down.
- The resulting **collisions** trigger the release of **electrons**, in a process very similar to the generation of electric sparks **(**this is called as **ionization** – an electron in the outer shell is pealed out of the atom and the atom become an ion. There are two types of ions based on charge – cation and anion. **Cation:** A cation is an atom or a molecule which is positively charged, i.e. has more number of protons than electrons. **Anion:** An anion is an atom or molecule which is negatively charged, i.e. has more number of electrons than protons**)**.
- The moving free electrons cause more collisions and more electrons, as a chain reaction ensues.
- The process results in a situation in which the top layer of the cloud gets positively charged (cations) while the middle layer is negatively (anions) charged.
- The electrical potential difference between the two layers is huge, of the order of 109 or 1010 volts.
- In little time, a huge current, of the order of 105 to 106 amperes, starts to flow between the layers.
- It produces heat, leading to the heating of the air column between the two layers of cloud.
- It is because of this **heat** that the air column looks red during lightning.
- The heated air column expands and produces **shock waves** that result in thunder.

Lightining from cloud to Earth

- Earth is a good conductor of electricity but is electrically neutral.

- In comparison to the middle layer of the cloud, however, it becomes positively charged.
- As a result, a flow of current (about 20-15%) gets directed towards the Earth as well.
- It is this current flow that results in the damage to life and property.
- There is a greater probability of lightning striking tall objects such as trees, towers or buildings.



- Once about 80-100 m from the surface, lightning tends to change course to hit the taller objects (guess why very tall buildings have a vertical pole above).

- This is because travelling through air, which is a bad conductor of electricity, electrons try to find a better conductor, and also the shortest route to the relatively positively charged Earth's surface.

Lightning deaths

- Several thousand thunderstorms occur over India every year.
- Incidents of lightning have been showing an increasing trend over the last 20 years, especially near the foothills of the Himalayas.
- People are rarely hit directly by lightning. But such strikes are almost always fatal.
- The most common way in which people are struck by lightning are by 'ground currents'.
- The electrical energy, after hitting a tree or any other object, spreads laterally on the ground for some distance, and people in this area receive electrical shocks.
- It becomes more dangerous if the ground is wet, or there is conducting material like metal on it.

Prediction and precautions

- Predicting a thunderstorm over a very precise location is not possible. Nor is the exact time that it is likely to strike.
- People are advised to move indoors in a storm.
- Moving under a tree or lying flat on the ground can increase risks.
- Even indoors, electrical fittings, wires, metal and water must be avoided.

The world's most electric place

- The most lightning activity on Earth is seen on the shore of **Lake Maracaibo** in **Venezuela**.
- At the place where the Catatumbo river falls into Lake Maracaibo, October sees 28 lightning flashes every minute — a phenomenon referred to as the Beacon of Maracaibo or the Everlasting Storm.

- The reason probably lies in the topography of the spot: winds blow across Lake Maracaibo — the **largest** in South America (By volume of water, Titicaca is the largest lake in South America. Lake Maracaibo has a larger surface area, though some consider it to be a large brackish bay due to its direct connection with the sea.) — which is surrounded by swampy plains and connected to the Gulf of Venezuela/Caribbean Sea by a very narrow strait.
- The Maracaibo plain is enclosed on three sides by high mountain sides into which air masses crash.
- The heat and moisture picked from the swampy plains creates electrical charges and, as the air is destabilized at the mountain faces, thunderstorm activity — characterised by almost non-stop lightning activity within clouds — results.

Deadly Strikes

- **Direct Strike:** Occurs most often in open areas.
- **Side Flash (Or Side Splash):** Occurs when lightning strikes a taller object and some current jumps on to the victim, who ends up acting as a "short circuit" for the energy.
- Generally occurs when the victim is within a foot or two of the struck object. Most victims are those sheltering under a tree in a rainstorm.
- **Ground Current:** When an object is struck, much of the energy travels outward in and along the ground surface. This is 'ground current', and anyone close can be a victim.
- Ground current affects a larger area than other kinds of current and causes the **most** lightning deaths and injuries.
- **Conduction:** Lightning can travel long distances in wires or other metal surfaces.
- Most indoor lightning casualties and some outdoor casualties are due to conduction.

Features of Lightning

- Positive charge accumulates at both higher and lower altitudes.
- Larger and heavier cloud particles charge with a negative polarity.
- Smaller and
- Roughly two-thirds of all discharges occur within the cloud. The rest are between the cloud and ground.

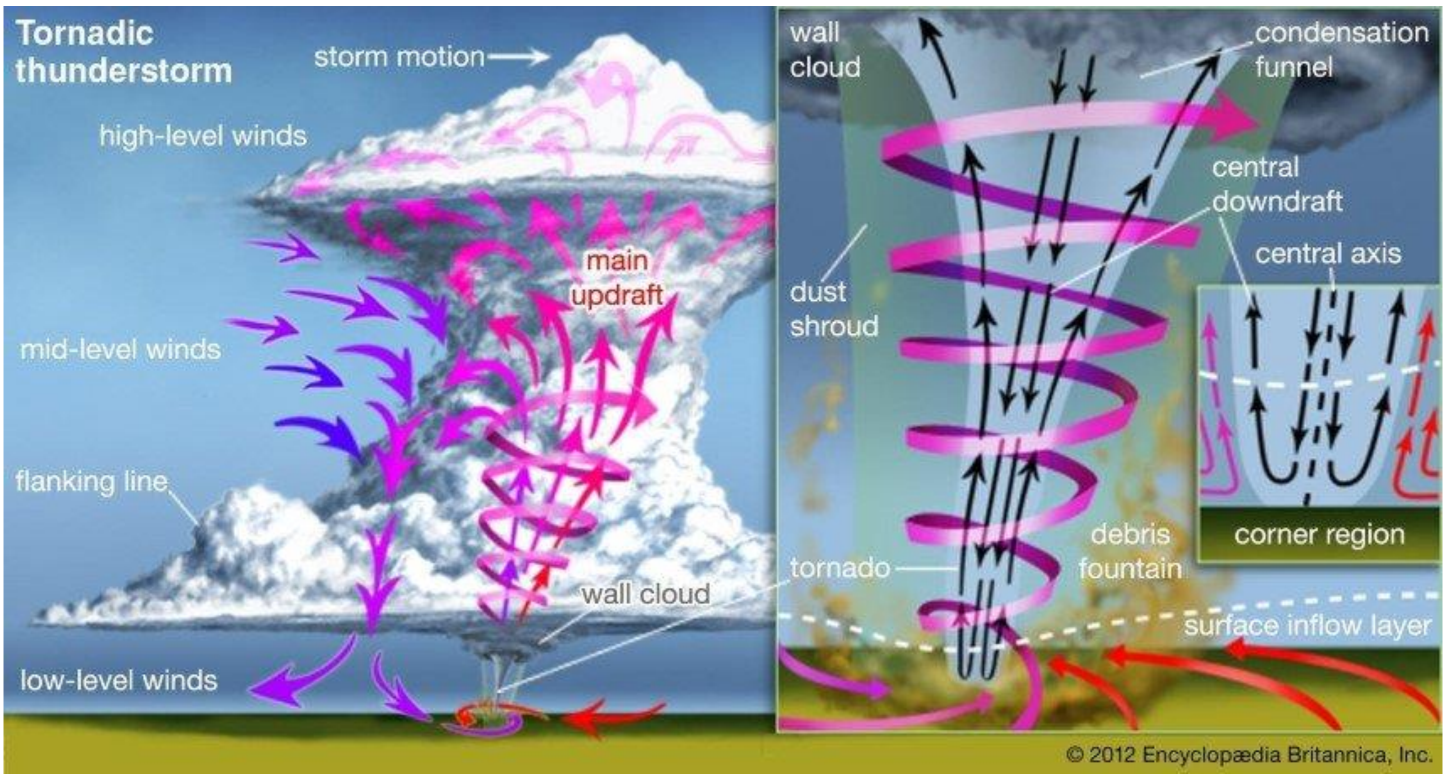
Thunder

- Lightning creates **plasma (ionized gas medium)** [30,000 °C].
- The channel pressure greatly exceeds the ambient (surrounding) pressure, and the channel expands at a **supersonic rate (speed of sound).**

- The resultant shock wave decays rapidly with distance and is eventually heard as thunder once it slows to the speed of sound.

  Source: http://indianexpress.com/article/explained/nuts-and-bolts-throwing-light-on-lightning-2872172/

Tornado

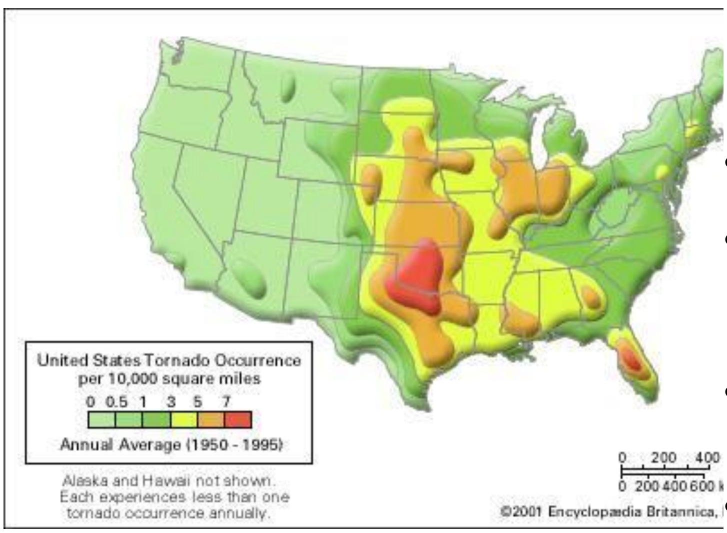


- From severe thunderstorms sometimes spiraling wind descends like a trunk of an elephant with great force, with very low pressure at the center, causing massive destruction on its way. Such a phenomenon is called a tornado.
- Tornadoes generally occur in **middle latitudes**. The tornado over the sea is called **water sprouts.**
- These violent storms are the manifestation of the atmosphere's adjustments to varying energy distribution. The potential and heat energies are converted into kinetic energy in these storms and the restless atmosphere again returns to its stable state.
- Tornado is a small-diameter column of violently rotating air developed within a convective cloud and in contact with the ground.
- Tornados occur most often in association with thunderstorms during the spring and summer in the mid-latitudes of both the Northern and Southern Hemispheres.
- These whirling atmospheric vortices can generate the strongest winds known on Earth: wind speeds in the range of 500 km (300 miles) per hour.

- They are often referred to as **twisters or cyclones.**

Distribution of tornadoes

- Rare in polar regions and infrequent at latitudes higher than 50° N and 50° S.
- The temperate and tropical regions are the most prone to thunderstorms.
- Tornadoes have been reported on all continents except Antarctica.
- United States has the most violent tornadoes.
- Canada reports the second largest number of tornadoes.
- In the Indian sub-continent, Bangladesh is the most prone country to tornadoes.
- At any moment there are approximately 1,800 thunderstorms in progress throughout the world.



Waterspout

- Waterspout is an intense columnar vortex (usually appearing as a funnel-shaped cloud) that occurs over a body of water.
- They are connected to a towering cumuliform cloud or a cumulonimbus cloud.
- Weaker than most of its land counterparts i.e. tornadoes.
- Most waterspouts do not suck up water; they are small and weak rotating columns of air over water.
- They are tornadoes in connection with severe thunderstorms, but simply occurring over water.

Damage caused by thunderstorms and tornadoes

- Many hazardous weather events are associated with thunderstorms.
- Under the right conditions, rainfall from thunderstorms causes flash flooding, killing more people each year than hurricanes, tornadoes or lightning.
- Lightning is responsible for many fires around the world each year, and causes fatalities.
- Hail up to the size of softballs damages cars and windows, and kills livestock caught out in the open.
- Strong (up to more than 120 mph) straight-line winds associated with thunderstorms knock down trees, power lines and mobile homes.
- Tornadoes (with winds up to about 300 mph) can destroy all but the best-built man-made structures.

Jet Streams – Geostrophic Wind – Upper Level Westerlies.

Geostrophic Wind

- The velocity and direction of the wind are the net result of the wind generating forces.
- The winds in the upper atmosphere, 2 - 3 km above the surface, are free from frictional effect of the surface and are controlled by the **pressure gradient** and the **Coriolis force.**
- An air parcel initially at rest will move from high pressure to low pressure because of the Pressure Gradient Force (PGF).

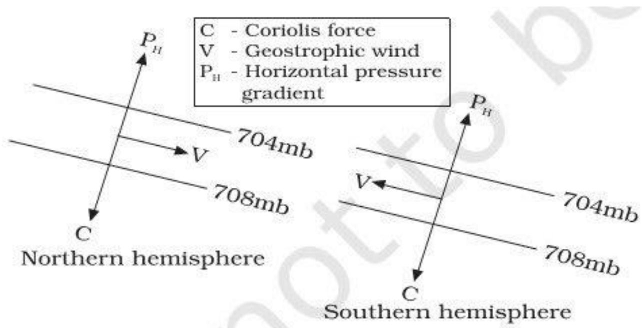
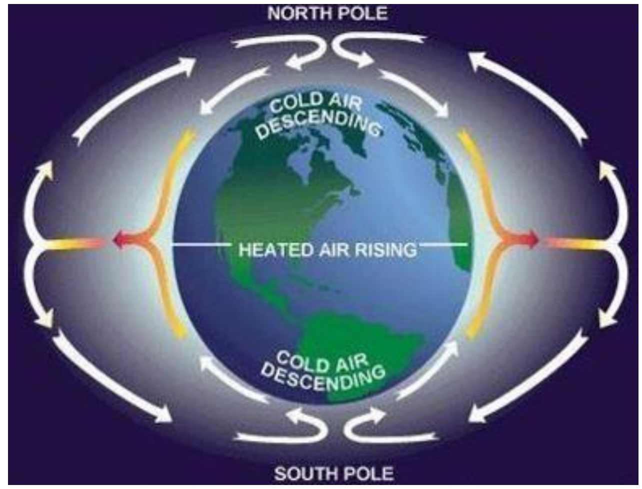


Figure 10.4 : Geostropic Wind

- However, as that air parcel begins to move, it is deflected by the Coriolis force to the **right in the northern hemisphere (to the left in the southern hemisphere).**
- As the wind gains speed, the deflection increases until the Coriolis force equals the pressure gradient force (2 – 3 km above the ground, friction is low and winds travel at greater speeds).
- At this point, the wind will be blowing parallel to the isobars (perpendicular to Pressure Gradient Force). When this happens, the wind is referred to as **geostrophic wind.**

Why winds don't flow from tropical high pressure (in upper troposphere) to polar low (in upper troposphere) directly as shown in figure below?

- Because these winds are geostrophic, i.e., they flow at great speeds due to low friction and are subjected to greater Coriolis force.
- So they deflect greatly giving rise to three distinct cells called Hadley cell, Ferrel Cell and Polar cell.
- Instead of one big cell (as shown in fig) we have three small cells that combinedly produces the same effect.



Jet streams

Jet streams are

- Circumpolar (situated around or inhabiting around one of the earth's poles),
- narrow, concentrated bands of
- meandering,
- upper tropospheric,
- high velocity,
- geostrophic streams,
- bounded by low speed winds and
- are a part of upper level westerlies.

Circumpolar

- Jet streams are winds that circle around the earth with poles as their centers.

Narrow, concentrated bands

- The stream of air is very narrow (50 -150 km across) and, the air in the stream is directed towards the axis of the stream making it very narrow.

Meandering

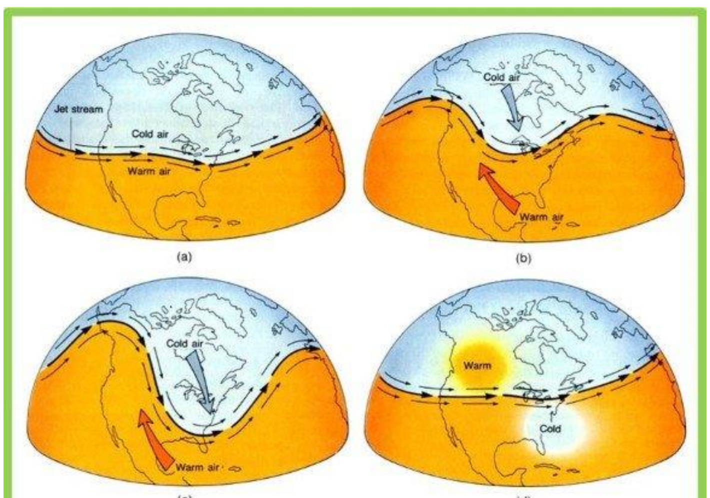


Figure 8•9 Cyclic changes that occur in the upper-level airflow of the westerlies. The flow, which has the jet stream as its axis, starts out nearly straight and then develops meanders that are eventually cut off. (After J. Namias, NOAA)

- When the temperature contrast is maximum, jet stream flows in near straight path.
- But when temperature contrast reduces, the jet stream starts to follow a meandering path.
- So meandering depends on **temperature contrast (temperature gradient).**
- A meander is called **peak or ridge** if it is towards poles and **trough** if it is towards equator.

Rossby Waves

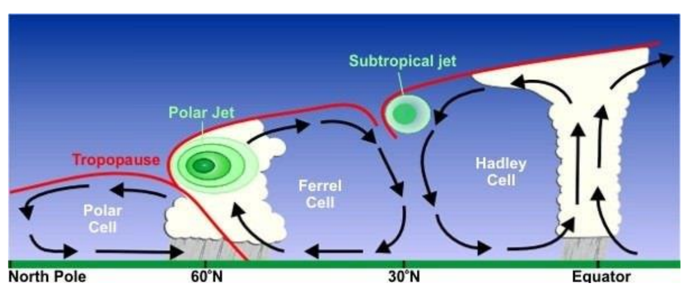
- The meandering jet streams are called **Rossby Waves.**
- Rossby waves are natural phenomenon in the atmosphere and oceans due to rotation of earth.
- In planetary atmospheres, they are due to the variation in the Coriolis effect (When temperature contrast is low, speed of jet stream is low, and Coriolis force is weak leading to meandering) with latitude.
- Rossby waves are formed when polar air moves toward the Equator while tropical air is moving poleward.
- The existence of these waves explains the low-pressure cells **(cyclones)** and high-pressure cells **(anticyclones)**.

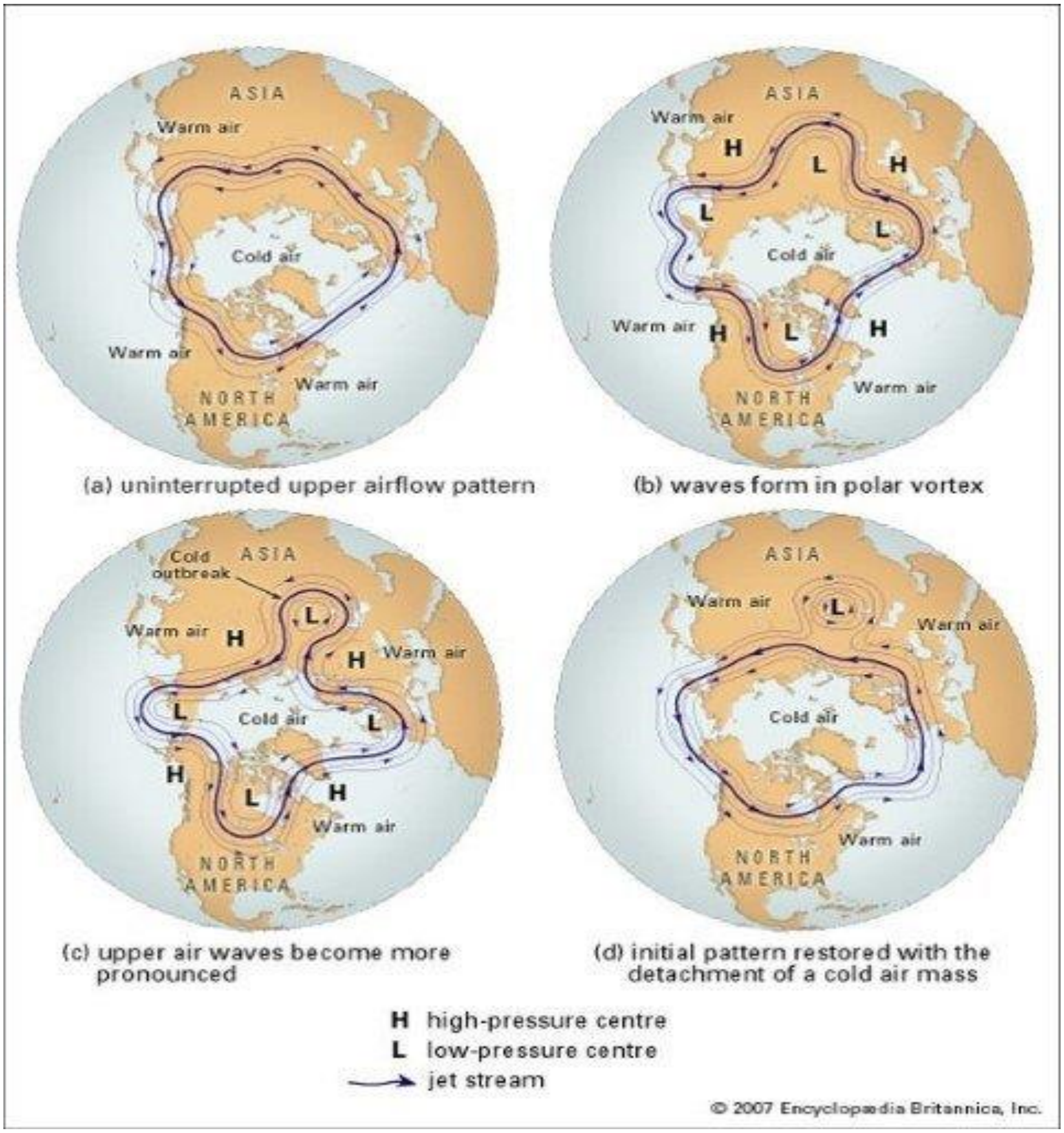
Upper Tropospheric

- Jet streams flow just below the Tropopause.
- Polar jet streams flow **6 – 9 km** above the ground and Sub-tropical jet streams flows **10 – 16 km** above the grounds.

Why this difference in height?

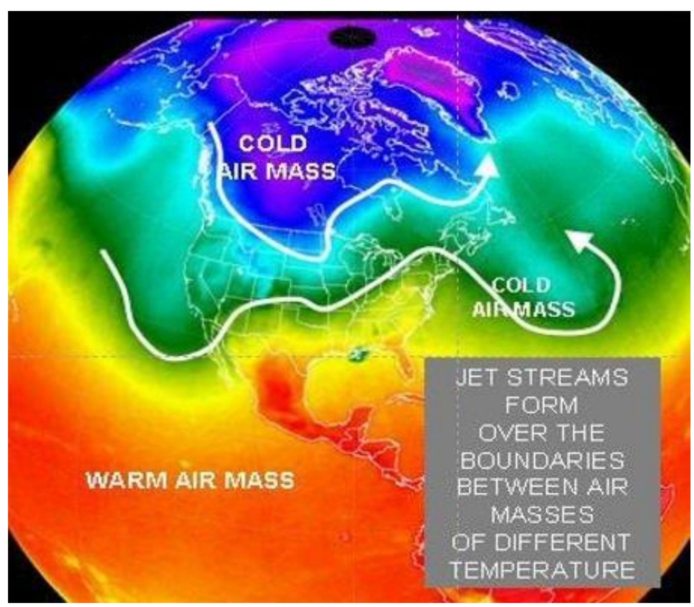
- Recall that troposphere is thicker at equator — 17 to 18 km, than at poles — 8 to 9 km.

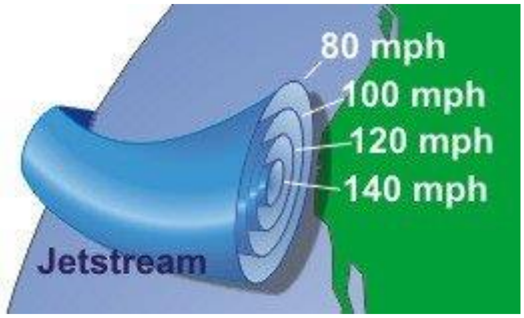




High velocity

- Pressure gradient increases with altitude and creates high velocity winds at higher altitudes.
- The friction in the upper troposphere is quite low due to less denser air. Hence the Jet streams flow at great velocities.
- Temperature also influences the velocity of the jet stream. The greater the difference in air temperature, the faster the jet stream, which can reach speeds of up to 250 mph (402 kph) or greater, but average about 110 mph (177 kph).
- The jet streams have an average velocity of 120 kilometres per hour in winter and 50 km per hour in summer. These jet streams also have cores where the speed is much greater.





Geostrophic streams

- Direction of the jet stream is determined by pressure gradient force (temperature contrast creates pressure gradients) and Coriolis force.
- The direction of jet stream is perpendicular to the pressure gradient force.

Bounded by low speed winds

- The winds surrounding jet streams are of comparatively low velocities.

Are a part of upper level westerlies

- Jet streams are produced due to winds flowing from tropics towards poles (In polar jet streams wind flows from temperate region towards polar region, and in sub-polar jet streams winds flow from sub-tropics towards temperate region).
- Anything moving from tropics towards poles deflects towards their right in the northern hemisphere and towards their left in the southern hemisphere due to Coriolis effect. So jet streams flow from west to east in both the hemispheres and hence they are called **westerlies or upper level westerlies.**
- Jet streams when weak move in the direction of westerlies in a wavy, irregular manner with a poleward or equator ward component.

Types of Jet streams – Permanent Jet Streams: Subtropical Jet Stream and Polar Jet Stream; Temporary Jet Streams: Tropical Easterly Jet or African Easterly Jet and Somali Jet. Impact of Jet Streams on Weather; Jet Streams and Aviation.

- Both the Northern and Southern hemispheres have jet streams, although the jet streams in the north are more forceful due greater temperature gradients.

Permanent jet streams

- There are two permanent jet streams – **subtropical jets** at lower latitudes and **polar front jets** at mid-latitudes.

Subtropical jet stream (STJ)

- The sub-tropical jet stream is produced by the earth's rotation (Coriolis force) and temperature contrast between **tropical and sub – tropical regions**.
- At the equator, the rotation produces greatest velocity in the atmosphere.
- As a result, the rising air which spreads out northwards and southwards, moves faster than the latitudes over which it is blowing.
- It is deflected to the right in the northern hemisphere and to the left in the southern hemisphere, and at about 30° latitude, it becomes concentrated as the subtropical jet streams.
- During winter, the STJ is nearly continuous in both hemispheres. The STJ exists all year in the southern hemisphere. However, it is intermittent in the northern hemisphere during summer when it migrates north.
- The STJ can be temporarily displaced when strong mid-latitude troughs extend into subtropical latitudes. When these displacements occur, the subtropical jet can merge with the polar front jet (Related

to Cloudbursts. We will study this in Indian Monsoons).

- STJ is closely connected to the Indian and African summer monsoons (We will study this in Indian Monsoons)

Polar front jet (PFJ)

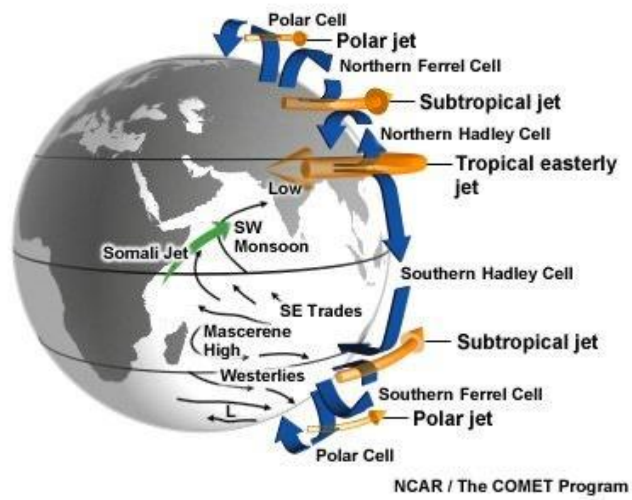
- The polar front jet is produced by a temperature difference and is closely related to the polar front (more about fronts later).
- It has a more variable position than the sub-tropical jet. In summer, its position shifts towards the poles and in winter towards the equator.
- The jet is strong and continuous in winter.
- It greatly influences climates of regions lying close to 60 degree latitude.
- It determines the path and speed and intensity of temperate cyclones.

Temporary jet streams

- While the polar and subtropical 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.

The Tropical Easterly Jet or African Easterly Jet

- There are also major high velocity winds in the lower troposphere called low-level jets (LLJs). In the tropics, the most prominent of these are the Somali Jet and the African Easterly Jet.
- The TEJ is a unique and dominant feature of the northern hemispheric summer over southern Asia and northern Africa. The TEJ is found near between 5° and 20°N.
- It is fairly persistent in its position, direction, and intensity from June through the beginning of October.
- During the south Asian summer monsoon, the TEJ induces secondary circulations that enhance convection over South India and nearby ocean.
- The establishment and maintenance of the TEJ is not fully understood but it is believed that the jet may be caused by the uniquely high temperatures and heights over the Tibetan Plateau during summer.
- The TEJ is the upper-level venting system for the strong southwest monsoon.



The Somali Jet

- Among the most well-known of the tropical LLJs is the Somali Jet, a **southwesterly** jet.
- The Somali jet occurs during the summer over northern Madagascar and off the coast of Somalia. The jet is most intense from June to August.
- It is a major cross-equatorial flow from the southern Indian Ocean to the central Arabian Sea.
- A split in the axis of the jet over the Arabian Sea, the more northern branch intersecting the west coast of India near 17°N, while the southerly branch moves eastward just south of India.
- The jet remains relatively steady from June to September before moving southward to the southern Indian Ocean during the winter.

Influence of Jet Streams on Weather

- Jet streams help in maintenance of latitudinal heat balance by mass exchange of air.

- PFJ influence the mid-latitude weather disturbances. Usually there are severe storms when jet streams interfere with surface wind systems.
- Jet streams also influence the path of temperate cyclones. They have an influence on distribution of precipitation by the **temperate cyclones.**
- Sub-tropical jet stream and some temporary jet streams together influence Indian Monsoon patterns. (more about this while studying India Monsoons in Indian geography)
- Jet streams also exercise an influence on movement of air masses which may cause **prolonged drought or flood conditions**.

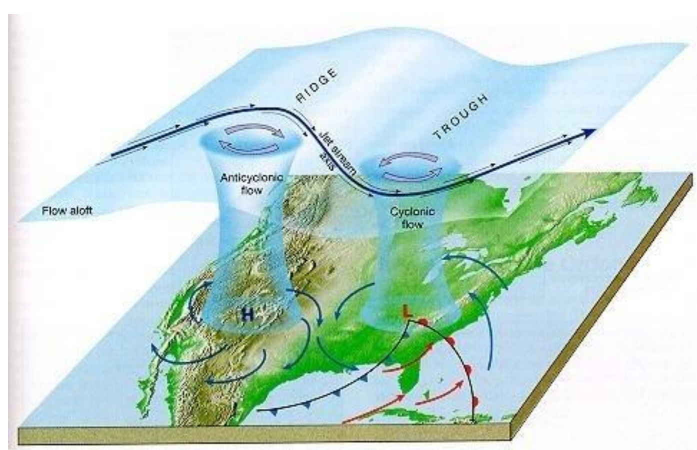
Jet Streams and Weather in Temperate Regions

How does jet streams affect the weather in temperate regions?

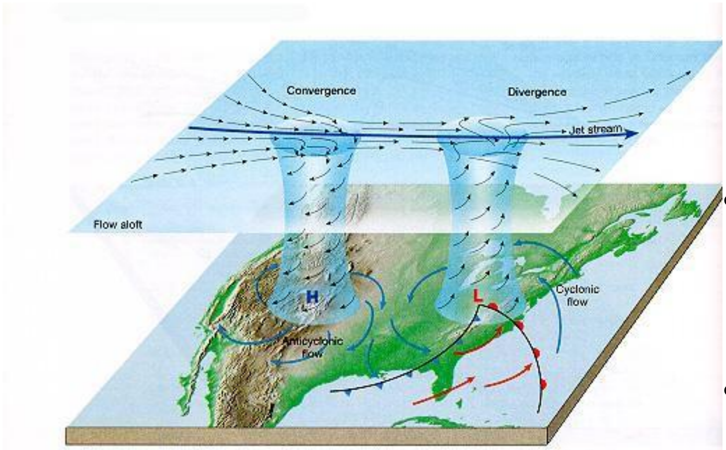
- PFJ play a key role in determining the weather because they usually separate colder air and warmer air.
- Jet streams generally push air masses around, moving weather systems to new areas and even causing them to stall if they have moved too far away.
- PFJ play a major role in determining the path and intensity of frontal precipitation and frontal cyclones or temperate cyclones.
- Weak PFJ also results in slipping of polar vortex into temperate regions. (More later)

Explanation

- Polar jet has distinct peaks (ridges) and troughs.
- Ridges occur where the warm air (at high pressure) pushes against the cold air.
- Troughs occur where cold air (at lower pressure) drops into warm air.
- This condition occurs due to weak jet stream which is weak due to lesser temperature contrast between sub-tropics and temperate region.
- These ridges and troughs give rise to jet streaks which are the main reason behind cyclonic and anticyclonic weather conditions at the surface.
- The winds leaving the jet streak are rapidly diverging, creating a lower pressure at the upper level (Tropopause) in the atmosphere. The air below rapidly replaces the upper outflowing winds. This in turn creates the low pressure at the surface. This surface low pressure creates conditions where the surrounding surface winds rush inwards. The Coriolis effect creates the cyclonic rotation that is associated with depressions.
- The winds entering the jet streak are rapidly converging, creating a high pressure at the upper level (Tropopause) in the atmosphere. This convergence at upper troposphere leads to divergence (high pressure) at the surface (anticyclonic condition).
- The Coriolis effect creates the anticyclonic rotation that is associated with clear weather.



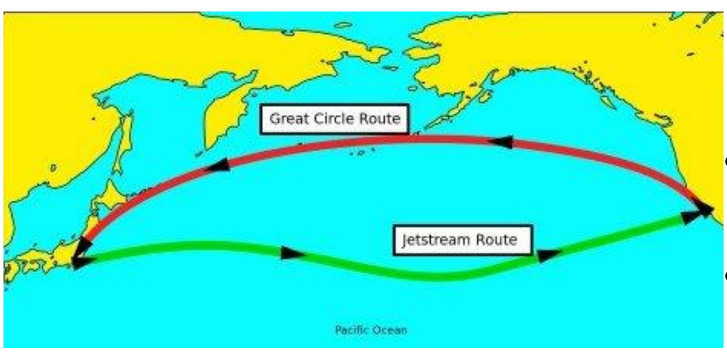
Vorticity provided by flow in the jet stream generates cyclonic flow near a trough and anticyclonic flow adjacent to a ridge.



Idealized depiction of the support that divergence and convergence aloft provide to cyclonic and anticyclonic circulation at the surface.

Jet Streams and Aviation

- Jet streams are used by aviators if they have to fly in the direction of the flow of the jet streams, and avoid them when flying in opposite direction.
- Jet streams can also cause a bumpy flight, because the jet stream is sometimes unpredictable and can cause sudden movement, even when the weather looks calm and clear.
- During volcanic eruptions plumes of volcanic ash have a tendency to get sucked into the same jet stream that airplanes use for travel.



Jet streams on other planets

- Other planets have jet streams as well, notably Jupiter and Saturn

Air masses - Source regions, Cold Air Mass, Warm Air Mass; Influence of Air Masses on World Weather; Classification of Air Masses: Continental Polar Air Masses (CP), Maritime Polar Air Masses (MP), Continental Tropical Air Masses (CT) and Maritime Tropical Air Masses (MT).

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.
- 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.***

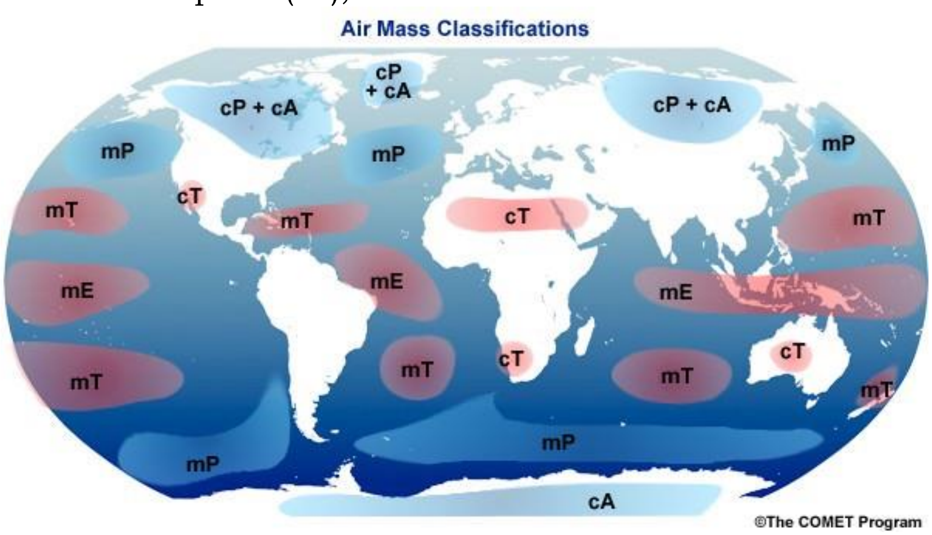
Air masses based on Source Regions

- 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.

Front - Front Formation: Frontogenesis; Front Dissipation: Frontolysis; Classification of Fronts: Stationary Front, Cold Front, Warm Front and Occluded Front.

Understanding Front Formation and Types of Fronts is important to understand the formation of **Mid-latitude cyclones [temperate cyclones or extra-tropical cyclones] and the dominant weather patterns of mid latitudes.**

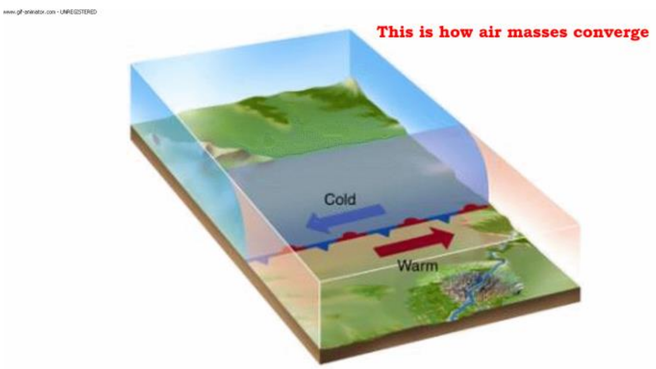
Fronts

- Fronts are the typical features of **midlatitudes weather (temperate region – 30° - 65° N and S).** They are uncommon (unusual) in tropical and polar regions.
- Front is a three dimensional **boundary zone formed between two converging air masses** with **different physical properties** (temperature, humidity, density etc.).
- The two air masses **don't merge readily** due to the effect of the converging atmospheric circulation, relatively low diffusion coefficient and a low thermal conductivity.

Front Formation

- The process of formation of a front is known as **Frontogenesis (war between two air masses)**, and dissipation of a front is known as **Frontolysis (one of the air masses win against the other).**

- Frontogenesis involves **convergence** of two distinct air masses. Frontolysis involves overriding of one of the air mass by another.
- In northern hemisphere **Frontogenesis** (convergence of air masses) happens in **anti-clockwise direction** and in southern hemisphere, **clockwise direction**. This is due to Coriolis effect.
- **Mid-latitude cyclones or temperate cyclones or extra-tropical cyclones occur due to frontogenesis.**



Gif Image

General Characteristics of Fronts

- The temperature contrast influences the thickness of frontal zone in an **inversely proportional manner**, i.e., two air masses with higher temperature difference do not merge readily. So the front formed is less thick.
- With a sudden change in temperature through a front, there is a change in pressure also.
- Front experiences wind shift, since the wind motion is a function of pressure gradient and Coriolis force.

  Wind Shift: A change in wind direction of 45 degrees or more in less than 15 minutes with sustained wind speeds of 10 knots or more throughout the wind shift.

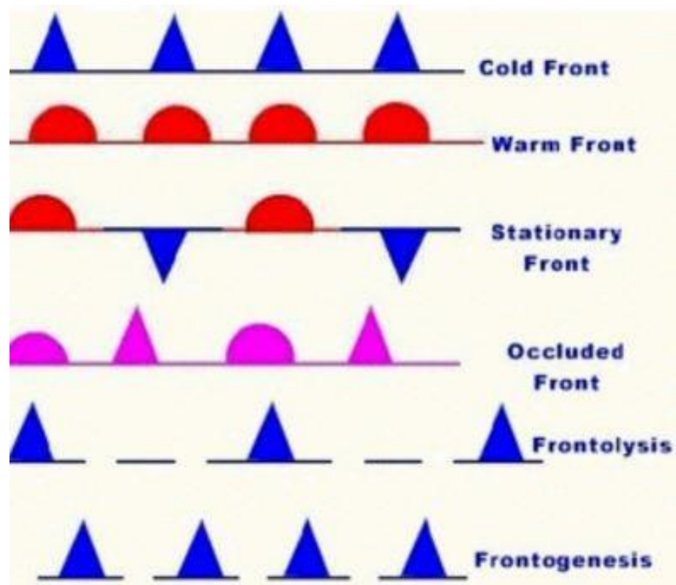
  1 knot = 1.852 kmph

  1 Nautical Mile = 1.852 km

- The frontal activity is invariably associated with **cloudiness and precipitation** because of ascent of warm air which cools down **adiabatically**, condenses and causes rainfall.
- The intensity of precipitation depends on the **slope of ascent and amount of water vapour present in ascending air.**

Classification of Fronts

- Based on the mechanism of frontogenesis and the associated weather, the fronts can be studied under the following types.

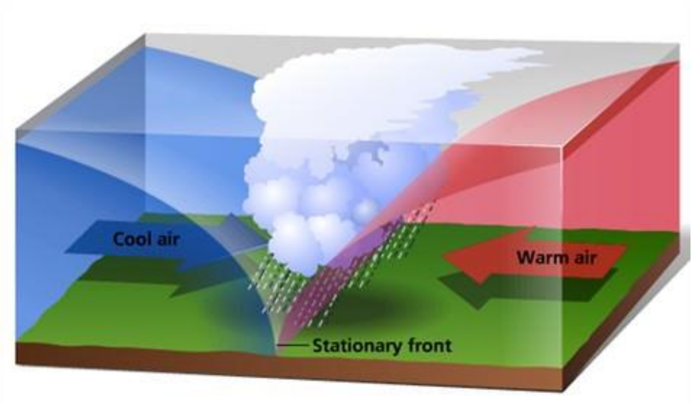


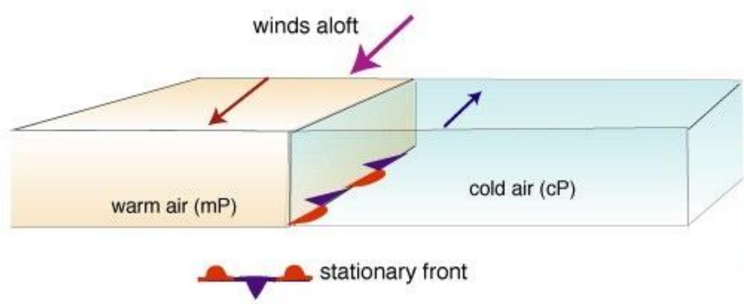
Stationary Front

- When the surface position of a front does not change (when two air masses are unable to push against each other; a draw), a stationary front is formed.
- The wind motion on both sides of the front is **parallel to the front**.
- Warm or cold front stops moving, so the name stationary front.
- Once this boundary resumes its forward motion, becomes a warm front or cold front.

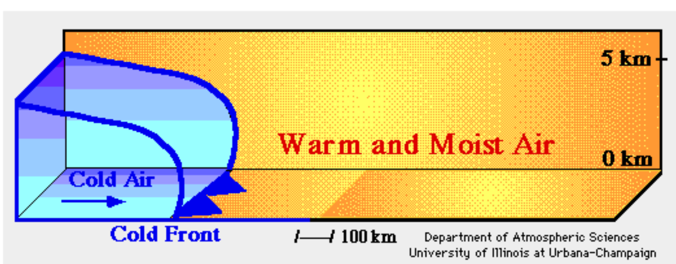
Weather along a stationary front

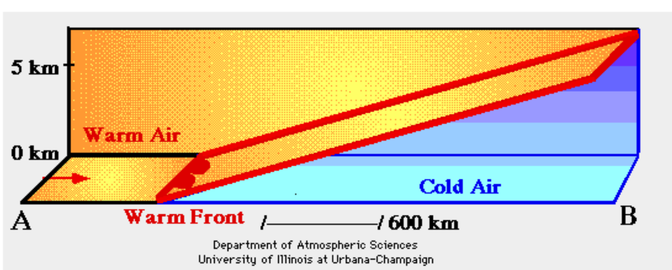
- Cumulonimbus clouds are formed. Overrunning of warm air along such a front causes **frontal precipitation**.
- Cyclones migrating along a stationary front can dump heavy amounts of precipitation, resulting in **significant flooding** along the front.





Cold and Warm Front Gif





Gif Images

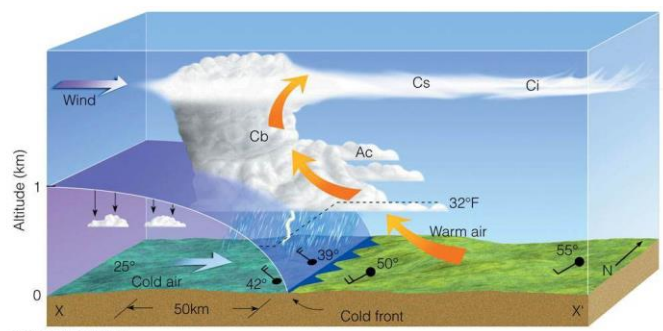
Cold Front

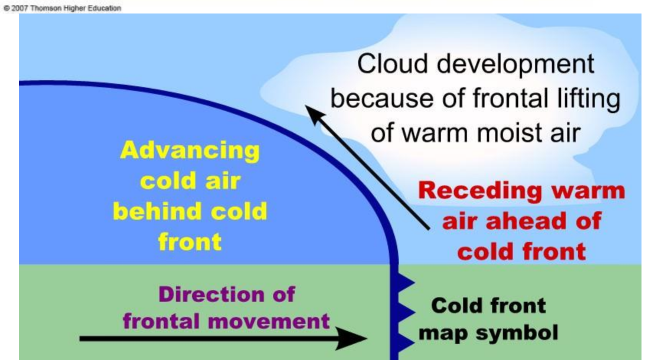
- Such a front is formed when a cold air mass replaces a warm air mass by advancing into it or that the warm air mass retreats and cold air mass advances (cold air mass is the clear winner).
- In such a situation, the transition zone between the two is a cold front.
- **Cold front moves up to twice as quickly as warm fronts**.
- Frontolysis begin when the warm air mass is completely uplifted by the cold air mass.

Weather along a cold front

- The weather along such a front depends on a narrow band of cloudiness and precipitation.
- Severe storms can occur. During the summer months **thunderstorms** are common in **warm sector.**

In some regions like USA **tornadoes** occur in warm sector.
Produce sharper changes in weather. Temperatures can drop more than 15 degrees within the first hour.

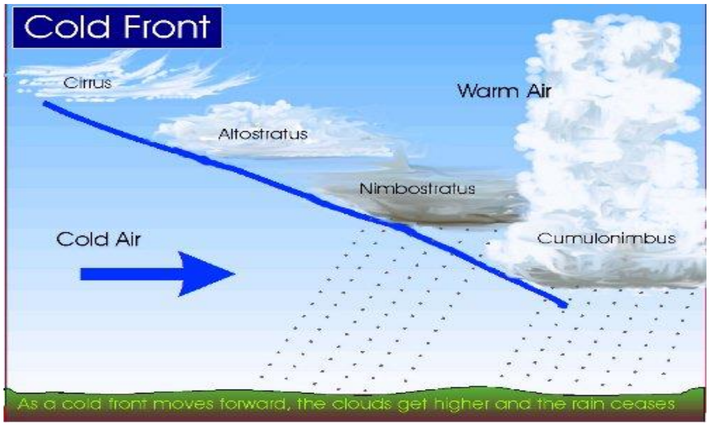




Cloud formation along a cold front

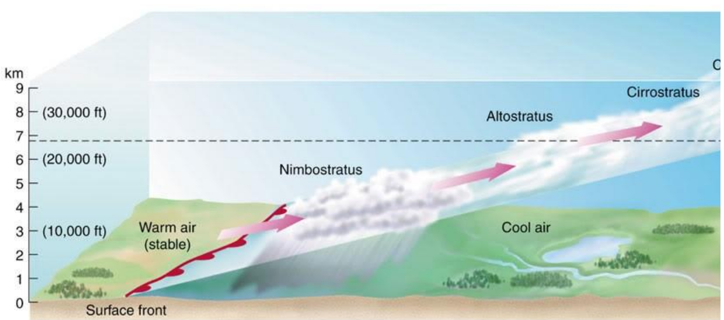
- The approach of a cold front is marked by increased wind activity in warm sector and the appearance of **cirrus clouds**, followed by lower, **denser altocumulous** and **altostratus.**

- At actual front, dark **nimbus and cumulonimbus clouds** cause heavy showers. A cold front passes off rapidly, but the **weather along it is violent**.



Warm Front

- It is a sloping frontal surface along which active movement of warm air over cold air takes place (warm air mass is too weak to beat the cold air mass).
- Frontolysis (front dissipation) begin when the warm air mass makes way for cold air mass on the ground, i.e. when the warm air mass completely sits over the cold air mass.



Weather along a warm front

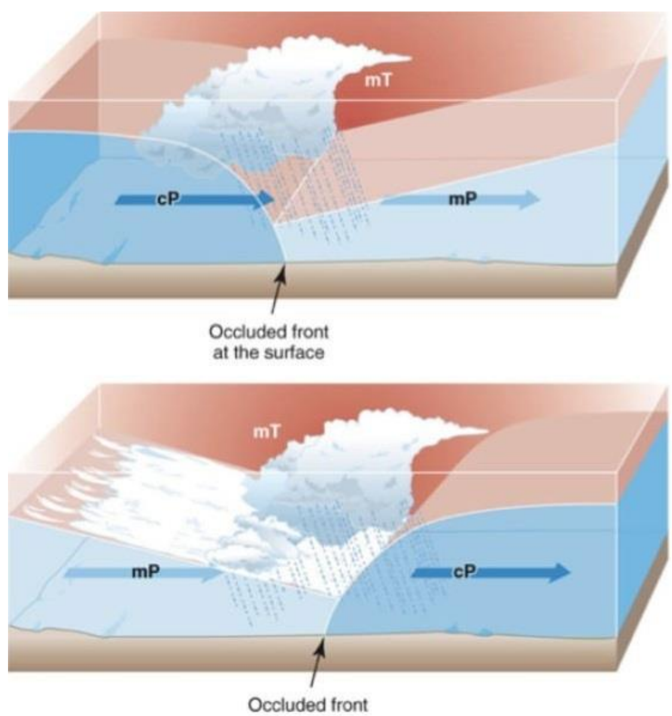
- As the warm air moves up the slope, it condenses and causes precipitation but, unlike a cold front, the temperature and wind direction changes are **gradual.**
- Such fronts cause **moderate to gentle precipitation** over a large area, over several hours.
- The passage of warm front is marked by **rise in temperature, pressure** and change in weather.

Clouds along a warm front

- With the approach, the hierarchy of clouds is—-cirrus, stratus and nimbus. [No cumulonimbus clouds as the gradient is gentle]
- **Cirrostratus clouds** ahead of the warm front create a halo around sun and moon.

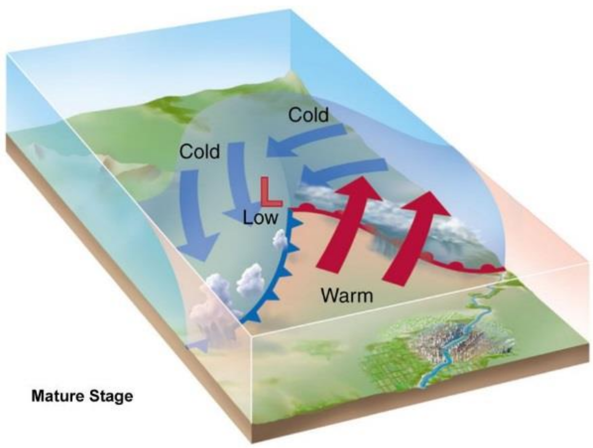
Occluded Front

- **Occlusion: Meteorology** a process by which the cold front of a rotating low-pressure system catches up the warm front, so that the warm air between them is **forced upwards.**
- Such a front is formed when a cold air mass overtakes a warm air mass and goes underneath it.
- Frontolysis begin when warm sector diminishes and the cold air mass completely undertakes the warm sector on ground.
- Thus, a long and backward swinging occluded front is formed which could be a **warm front type or cold front type occlusion**.



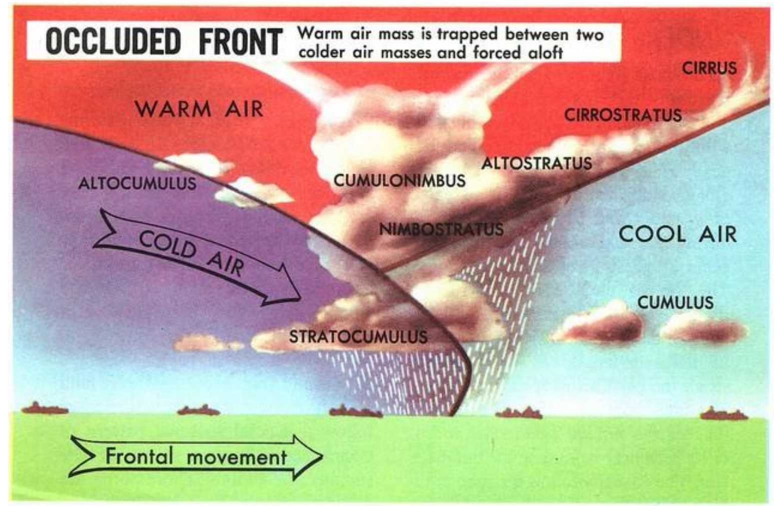
Weather along an occluded front

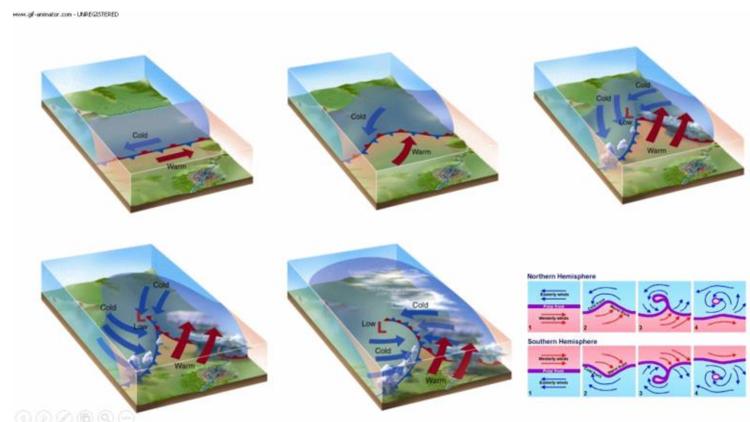
- Weather along an occluded front is complex—a **mixture of cold front type and warm front type weather**. Such fronts are common in west Europe.
- The formation **Mid-latitude** cyclones [temperate cyclones or extra-tropical cyclones] involve the formation of **occluded front**.



Clouds along an occluded front

- A combination of clouds formed at cold front and warm front.
- Warm front clouds and cold front clouds are on opposite side of the occlusion





Gif Image

Stationary Front	*Tie = No clear Winner*
Cold Front	*Cold Air mass is the clear winner.*
Warm Front	*The warm air mass picks up a fight but fails to beat the cold air mass.* *Cold Air mass is the winner.*
Occluded Front	*Cold Front + Warm Front* *Double win for cold air mass*
Cold Front, Warm Front and Occluded front are examples of Temperature Inversion.	

In this post: Tropical Cyclones – Favorable conditions for the development of tropical cyclones, Origin and Development of Tropical Cyclones, Structure and Characteristics of a Tropical Cyclone, Categories of Tropical Cyclones etc..

Tropical Cyclones

- Tropical cyclones are violent storms that originate over oceans in **tropical areas** and move over to the coastal areas bringing about large scale destruction due to violent winds (squalls), very heavy rainfall (torrential rainfall) and **storm surge**.
- They are irregular wind movements involving **closed circulation** of air around a low pressure center. This closed air circulation (whirling motion) is a result of **rapid upward movement of hot air** which is subjected to **Coriolis force**. The low pressure at the center is responsible for the wind speeds.

Squall == a sudden violent gust of wind or localized storm, especially one bringing rain, snow, or sleet.

Torrent == a strong and fast-moving stream of water or other liquid.

- The cyclonic wind movements are **anti-clockwise in the northern hemisphere** and **clockwise in the southern hemisphere** (This is due to **Coriolis force**).
- The cyclones are often characterized by existence of an anticyclone between two cyclones.

Conditions Favourable for Tropical Cyclone Formation

1. Large sea surface with temperature higher than **27° C**,
2. Presence of the Coriolis force enough to create a cyclonic vortex,
3. Small variations in the vertical wind speed,
4. A pre-existing weak low-pressure area or low-level-cyclonic circulation,
5. Upper divergence above the sea level system,

Good Source of Latent Heat

- Ocean waters having temperatures of 27° C or more is the source of moisture which feeds the storm. The condensation of moisture releases enough **latent heat of condensation** to drive the storm.

Why tropical cyclones form mostly on the western margins of the oceans? OR

Why tropical cyclones don't form in the eastern tropical oceans?

- The depth of warm water **(26-27°C)** should extend for **60-70 m** from surface of the ocean/sea, so that deep convection currents within the water do not churn and mix the cooler water below with the warmer water near the surface.
- The above condition occurs only in western tropical oceans because of warm ocean currents (easterly trade winds pushes ocean waters towards west) that flow from east towards west forming a thick layer of water with temperatures greater than 27°C. This supplies enough moisture to the storm.
- The **cold currents** lower the surface temperatures of the eastern parts of the tropical oceans making them unfit for the breeding of cyclonic storms.

[One Exception: During strong El Nino years, strong hurricanes occur in the eastern Pacific. This is due to the accumulation of warm waters in the eastern Pacific due to **weak Walker Cell**]

Why cyclones occur mostly in late summers?

- Whirling motion is enhanced when the **doldrums** (region within ITCZ) over oceans are farthest from the equator. This happens during the autumnal equinox (August-September). At this time, there are two advantages—the air is overheated and the sun is exactly over the equator.

[Due to high specific heat of water, and mixing, the ocean waters in northern hemisphere attain maximum temperatures in August. (Continents attain maximum temperatures in June-July)]

Coriolis Force (f)

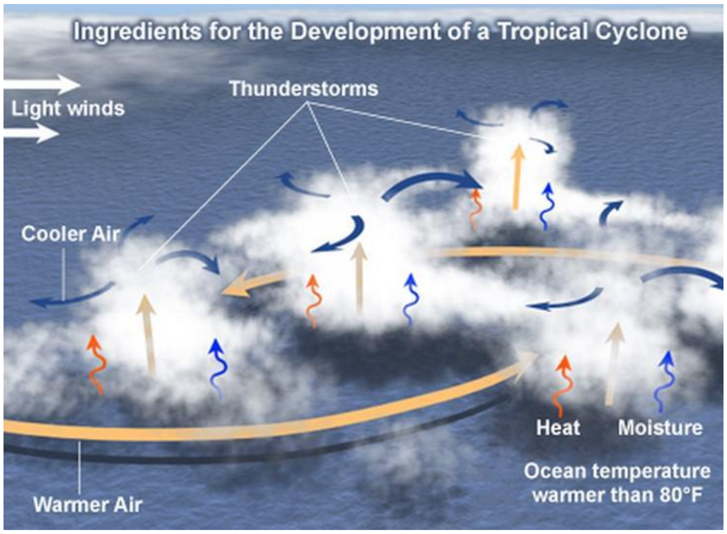
- The **Coriolis force is zero at the equator (no cyclones at equator because of zero Coriolis Force)** but it increases with latitude. Coriolis force at **5°** latitude is significant enough to create a storm [cyclonic vortex].
- **About 65 per cent of cyclonic activity occurs between 10° and 20° latitude**.

Low-level Disturbances

- Low-level disturbance (thunderstorms – they are the seeds of cyclones) in the form of easterly wave disturbances in the Inter-Tropical Convergence Zone (ITCZ) should pre-exist.
- **Small local differences** in the temperature of water and of air produce various **low pressure centers** of small

size. A weak cyclonic circulation develops around these areas.

- Then, because of the rising warm humid air, a true cyclonic vortex may develop very rapidly. However, only a few of these disturbances develop into cyclones.



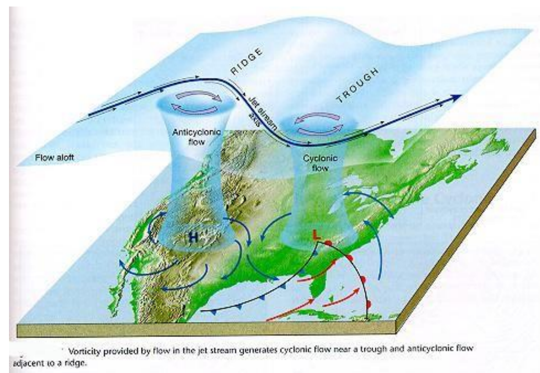
[rising of humid air => adiabatic lapse rate => fall in temperature of air => condensation of moisture in air => latent heat of condensation released => air gets more hot and lighter => air is further uplifted => more air comes in to fill the gap => new moisture available for condensation => latent heat of condensation and the cycle repeats]

Temperature contrast between air masses

- Trade winds from both the hemispheres meet along inter-tropical front. Temperature contrasts between these air masses must exist when the ITCZ is farthest, from the equator.
- Thus, the convergence of these air masses of different temperatures and the resulting instability are the prerequisites for the origin and growth of violent tropical storms.

Upper Air Disturbance

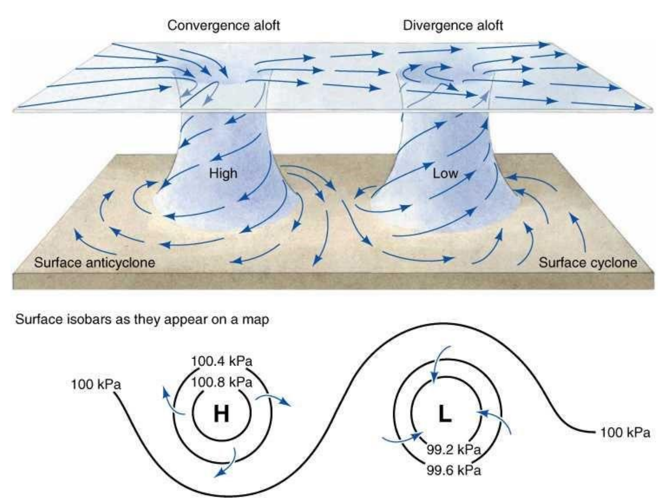
- The remains of an upper tropospheric cyclone from the Westerlies move deep into the tropical latitude regions. As divergence prevails on the eastern side of the troughs, a rising motion occurs; this leads to the development of thunderstorms.
- Further, these old abandoned troughs (remnants of temperate cyclones) usually have cold cores, suggesting that the environmental lapse rate is steeper and unstable below these troughs. Such instability encourages thunderstorms (child cyclones).



Wind Shear

- Wind Shear == differences between wind speeds at different heights.
- Tropical cyclones develop when the wind is uniform.
- **Because of weak vertical wind shear, cyclone formation processes are limited to latitude equator ward of the subtropical jet stream.**
- In the temperate regions, wind shear is high due to westerlies and this inhibits convective cyclone formation.

Upper Tropospheric Divergence



- A well - developed divergence in the upper layers of the atmosphere is necessary so that the rising air currents within the cyclone continue to be pumped out and a low pressure maintained at the center.

Humidity Factor

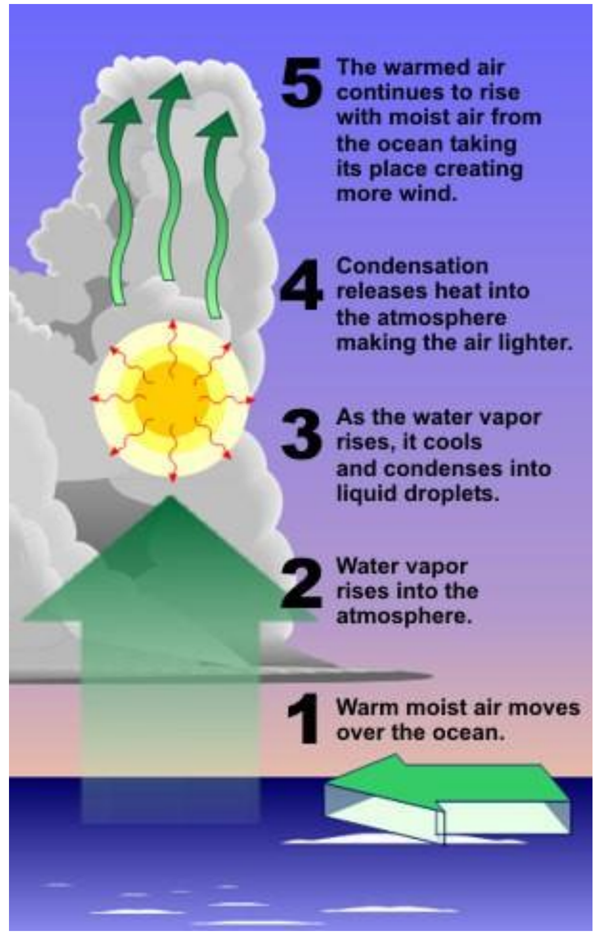
- High humidity (around 50 to 60 per cent) is required in the mid-troposphere, since the presence of moist air leads to the formation of **cumulonimbus cloud**.
- Such conditions exist over the equatorial **doldrums**, especially in western margins of oceans (this is because of east to west movement of ocean currents), which have great moisture, carrying capacity because the **trade winds** continuously replace the saturated air.

Origin and Development of Tropical Cyclones

- The tropical cyclones have a **thermal origin**, and they develop over tropical seas during late summers (August to mid-November).
- At these locations, the strong local convectional currents acquire a whirling motion because of the Coriolis force.
- After developing, these cyclones advance till they find a weak spot in the trade wind belt.

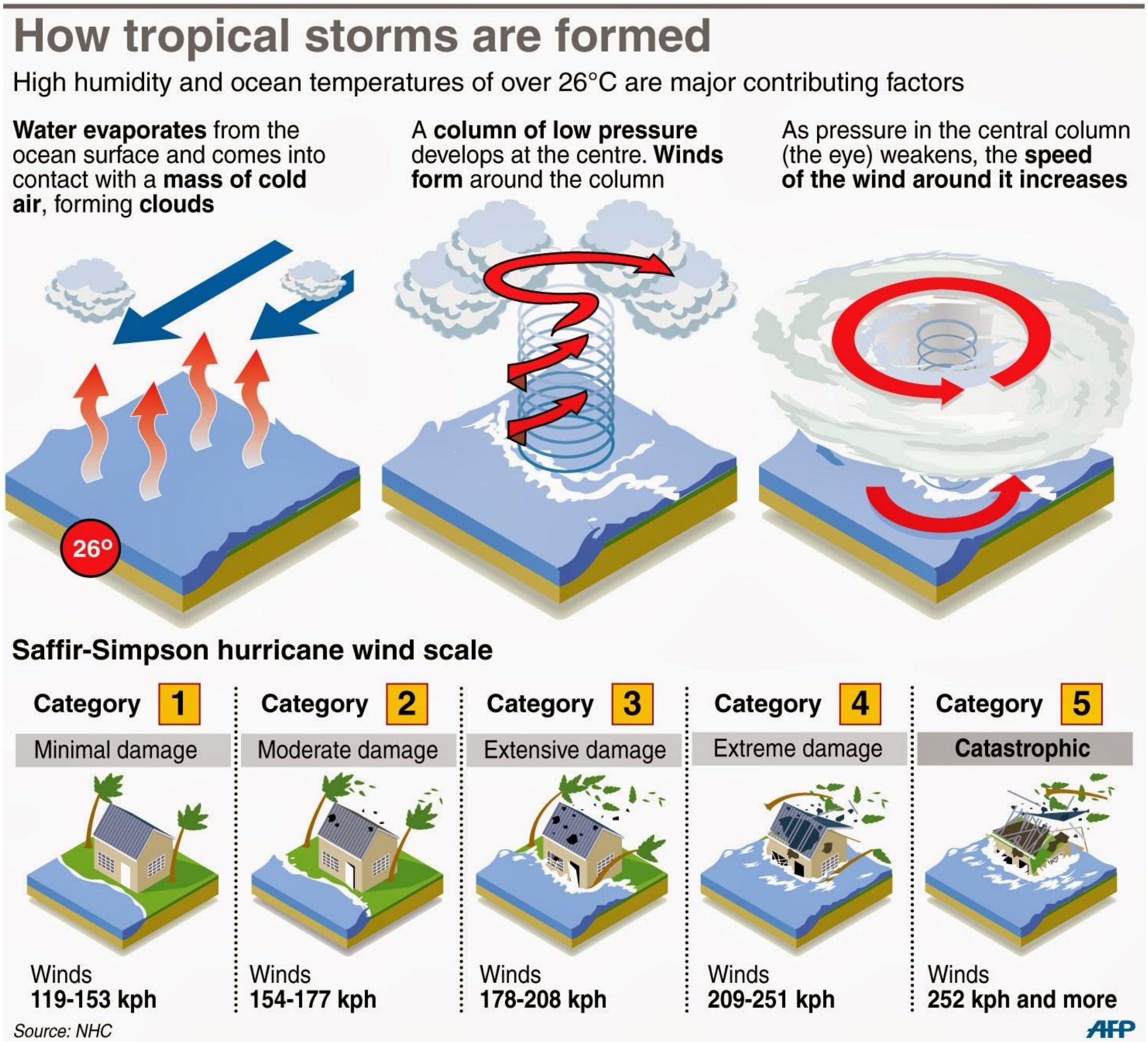
Origin

- Under favorable conditions, multiple thunderstorms originate over the oceans. These thunderstorms merge and create an intense low pressure system (wind is warm and lighter).



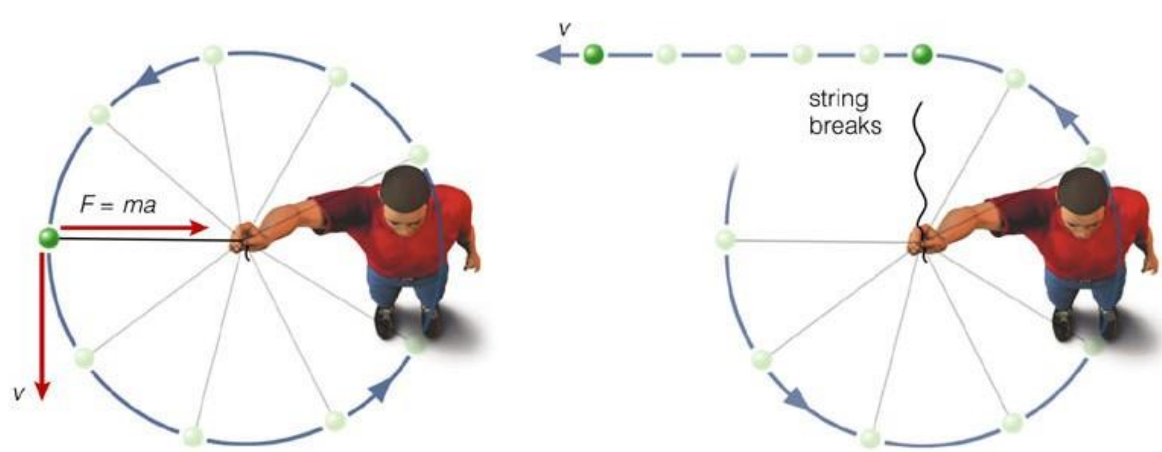
Early stage

- In the thunderstorm, air is uplifted as it is **warm and light**. At certain height, due to **lapse rate and adiabatic lapse rate**, the temperature of air falls and moisture in the air undergoes **condensation**.
- Condensation releases **latent heat of condensation** making the air more warmer. It becomes much lighter and is further uplifted.
- The space is filled by fresh moisture laden air. Condensation occurs in this air and the cycle is repeated as long as the moisture is supplied.
- Due to excess moisture over oceans, the thunderstorm intensifies and sucks in air at much faster rate. The air from surroundings rushes in and undergoes deflection due to **Coriolis force** creating a **cyclonic vortex (spiraling air column. Similar to tornado).**



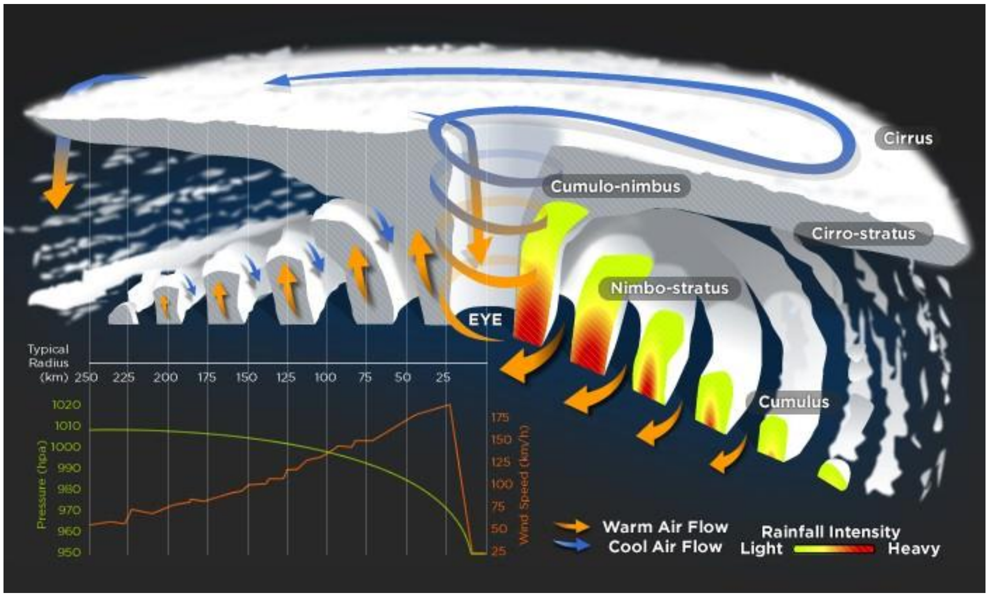
- Due to centripetal acceleration (centripetal force pulling towards the center is countered by an opposing force called centrifugal force), the air in the vortex is forced to form a region of calmness called an **eye** at the center of the cyclone. The inner surface of the vortex forms the **eye wall**, the **most violent region** of the cyclone.

[Eye is created due to tangential force acting on wind that is following a curvy path]



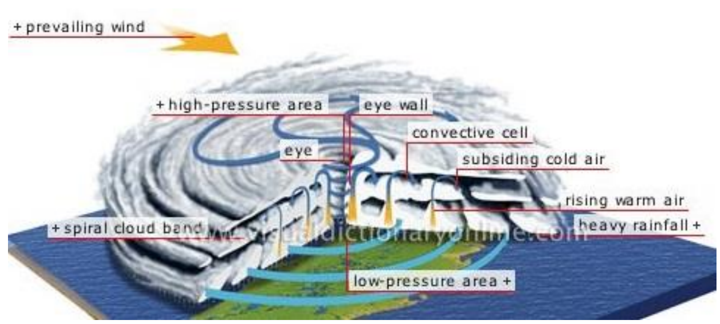
- All the wind that is carried upwards loses its moisture and becomes cold and dense. It descends to the surface through the cylindrical eye region and at the edges of the cyclone.
- Continuous supply of **moisture** from the sea is the major driving force behind every cyclone. On reaching the land the **moisture supply is cut off** and the storm dissipates.
- If ocean can supply more moisture, the storm will reach a mature stage.

Mature stage



- At this stage, the spiraling winds create multiple convective cells with successive calm and violent regions.
- The regions with cumulonimbus cloud (rising limbs of convective cell) formation are called **rain bands** below which intense rainfall occurs.
- The ascending air will lose moisture at some point and descends (subsides) back to surface through the calm regions (descending limbs of convection cell – subsiding air) that exist between two rain bands.
- Cloud formation is dense at the center. The cloud size decreases from center to periphery.
- Rain bands are mostly made up of cumulonimbus clouds. The ones at the periphery are made up of nimbostratus and cumulus clouds.
- The dense overcast at the upper levels of troposphere is due to **cirrus clouds** which are mostly made up of hexagonal ice crystals.
- The dry air flowing along the central dense overcast descends at the periphery and the eye region.

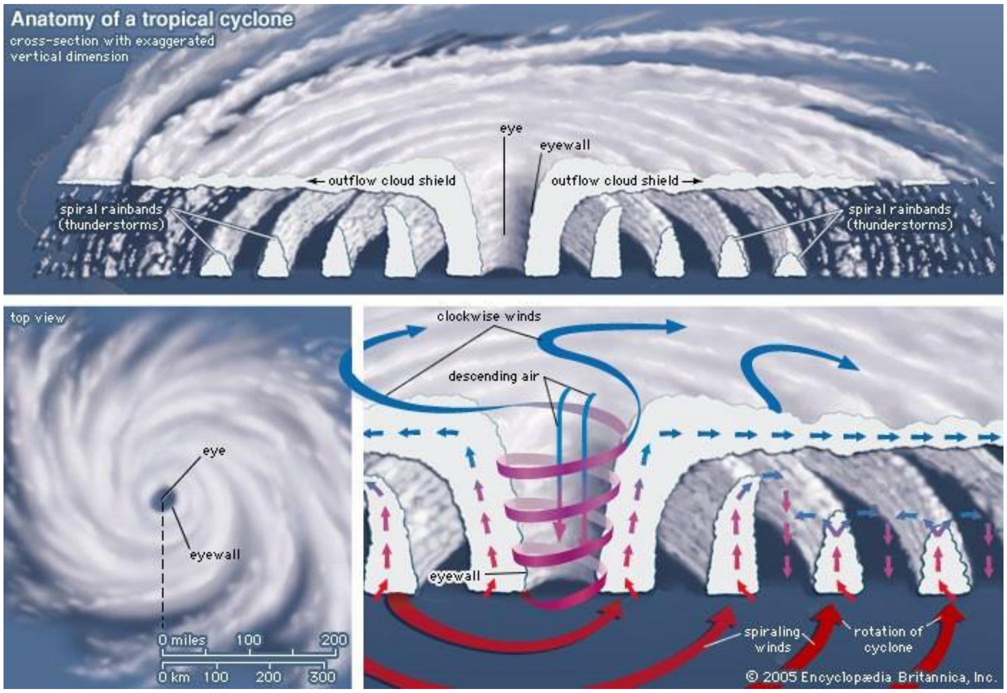
Structure of a tropical cyclone



Eye

- The "eye" is a roughly circular area of comparatively **light winds and fair weather** found at the center of a severe tropical cyclone.
- There is little or **no precipitation** and sometimes blue sky or stars can be seen.
- The eye is the region of **lowest surface pressure** and warmest temperatures aloft (in the upper levels) - the eye temperature

may be 10°C warmer or more at an altitude of 12 km than the surrounding environment, but only 0-2°C warmer at the surface in the tropical cyclone.



Eyes range in size from 8 km to over 200 km across, but most are approximately 30-60 km in diameter.

Eye wall

- The eye is surrounded by the "eye wall", the roughly circular ring of **deep convection**, which is the area of **highest surface winds** in the tropical cyclone. Eye Wall region also sees the maximum sustained winds i.e. **fastest winds in a cyclone occur along the eye wall region.**
- The eye is composed of air that is slowly sinking and the eye wall has a net upward flow as a result of many moderate - occasionally strong - **updrafts and downdrafts [Explained in 'Thunderstorms']**.
- The eye's warm temperatures are due to compressional warming (adiabatic) of the subsiding air.
- Most soundings taken within the eye show a low-level layer, which is relatively moist, with an inversion above - suggesting that the sinking in the eye **typically does not reach the ocean surface**, but instead only gets to around 1-3 km of the surface.

Spiral bands

Another feature of tropical cyclones that probably plays a role in **forming and maintaining the eye** is the eye wall convection. Convection in tropical cyclones is organized into long, narrow rain bands which are oriented in the same direction as the horizontal wind.

Because these bands **seem to spiral into the center** of a tropical cyclone, they are called "spiral bands".

Along these bands, low-level convergence is a maximum, and therefore, upper-level divergence is most pronounced above.

- A direct circulation develops in which warm, moist air converges at the surface, ascends through these bands, **diverges aloft**, and **descends on both sides of the bands**.
- Subsidence is distributed over a wide area on the outside of the rain band but is concentrated in the small inside area.
- As the air subsides, adiabatic warming takes place, and the air dries.
- Because subsidence is concentrated on the inside of the band, the adiabatic warming is stronger inward from the band causing a sharp contrast in pressure falls across the band since warm air is lighter than cold air.
- Because of the pressure falls on the inside, the tangential winds around the tropical cyclone increase due to increased pressure gradient. Eventually, the band moves toward the center and encircles it and the **eye and eye wall form**.
- Thus, the cloud-free eye may be due to a **combination of dynamically forced**

centrifuging of mass out of the eye into the eye wall and to a forced descent caused by the moist convection of the eye wall.

Vertical Structure of a Tropical Cyclone

There are three divisions in the vertical structure of tropical cyclones.

The lowest layer, extending up to 3 km and known as the inflow layer, is responsible for **driving the storm**.

- The middle layer, extending from 3 km to 7 km, is where the **main cyclonic storm** takes place.
- The outflow layer lies above 7 km. The maximum outflow is found at 12 km and above. The movement of air is **anticyclonic** in nature.

Categories of Tropical Cyclones

Cyclone Category	Wind Speed in Km/h	Damage Capacity
01	120-150	Minimal
02	150-180	Moderate
03	180-210	Extensive
04	210-250	Extreme
05	250 +	Catastrophic

Type of Disturbances	Wind Speed in Km/h
Low Pressure	Less than 31
Depression	31-49
Deep Depression	49-61
Cyclonic Storm	61-88
Severe Cyclonic Storm	88-117
Very Severe Cyclone	118-221
Super Cyclone	More than 221

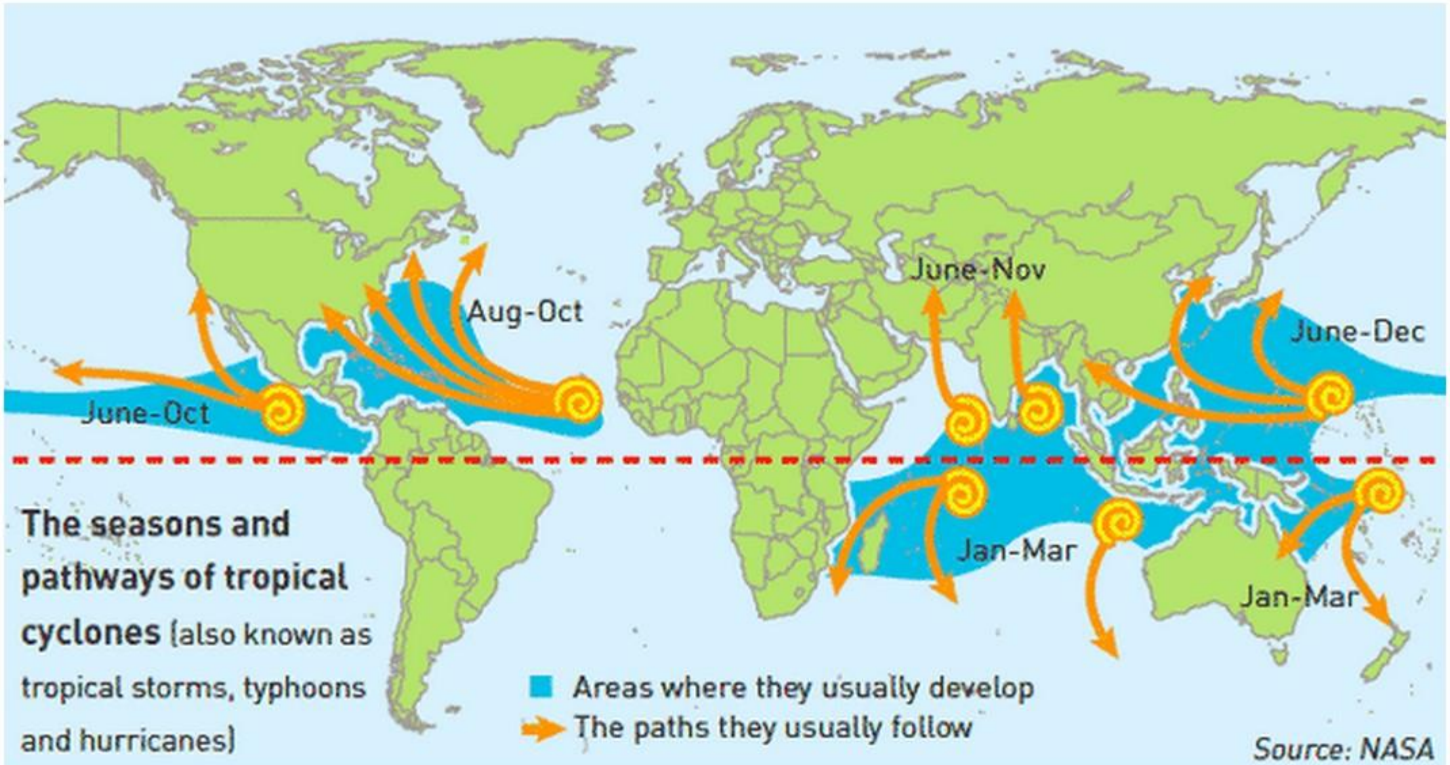
Favorite Breeding Grounds for Tropical Cyclones

- South-east Caribbean region where they are called hurricanes.
- Philippines islands, eastern China and Japan where they are called typhoons.
- Bay of Bengal and Arabian Sea where they are called cyclones.
- Around south-east African coast and Madagascar-Mauritius islands.
- North-west Australia.

Regional names for Tropical Cyclones

Category	Australian name	US*	NW Pacific	Arabian Sea /Bay of Bengal
-	Tropical low	Tropical depression	Tropical depression	Depression or severe depression
1	Tropical cyclone	Tropical storm	Tropical storm	Cyclonic storm
2	Tropical cyclone	Tropical storm	Severe tropical storm	Severe cyclonic storm
3	Severe tropical Cyclone	Hurricane	Typhoon	Very severe cyclonic storm
4	Severe tropical cyclone	Hurricane	Typhoon	Very severe cyclonic storm
5	Severe tropical cyclone	Hurricane	Typhoon	Super cyclonic storm

Regions	What they are called
Indian Ocean	Cyclones
Atlantic	Hurricanes
Western Pacific and South China Sea	Typhoons
Western Australia	Willy-willies



Characteristics of Tropical Cyclones

- The main features of tropical cyclones are as follows.

Size and Shape

- Tropical cyclones have symmetrical **elliptical shapes** (2:3 ratio of length and breadth) with steep pressure gradients. They have a compact size—80 km near center, which may develop up to 300 km to 1500 km.

Wind Velocity and Strength

- Wind velocity, in a tropical cyclone, is more in poleward margins than at center and is more over oceans than over landmasses, which are scattered with physical barriers. The wind velocity may range from nil to 1200 km per hour.

Path of Tropical Cyclones

- These cyclones start with a westward movement, but turn northwards around 20° latitude. They turn further north-eastwards around 25° latitude, and then eastwards around 30° latitude. They then lose energy and subside.
- Tropical cyclones follow a **parabolic path**, their axis being parallel to the isobars.
- Coriolis force or earth's rotation, easterly and westerly winds influence the path of a tropical cyclone.
- Tropical cyclones die at 30° latitude because of cool ocean waters and increasing wind shear due to westerlies.

Warning of Tropical Cyclones

- Detection of any unusual phenomena in the weather leading to cyclones has three main parameters: **fall in pressure, increase in wind velocity, and the direction and movement (track) of storm.**
- There are a network of weather stations monitoring pressure fall and wind velocities in all countries of the world, including the Arctic and Antarctic regions.

- The islands attain special significance in this as they facilitate monitoring of these developments.
- In India, there are detection radars along both the coasts.
- Monitoring is also done by aircraft which carry a number of instruments including a weather radar.
- Cyclone monitoring by satellites is done through very high resolution radiometers, working in the visual and infra-red regions (for night view) of the spectrum to obtain an image of the cloud cover and its structure.
- Remote sensing by radars, aircraft and satellites helps predict where exactly the cyclone is going to strike. It helps in taking advance steps in the following areas:

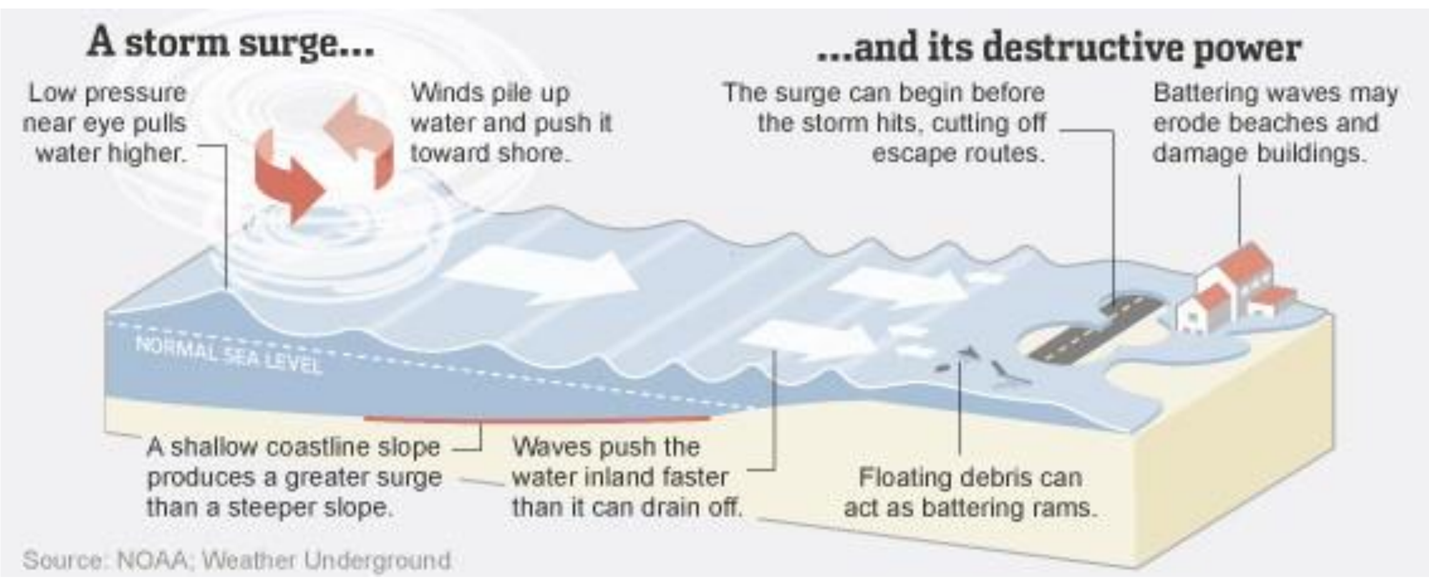
1. closing of ports and harbours,
2. suspension of fishing activities,
3. evacuation of population,
4. stocking of food and drinking water, and
5. provision of shelter with sanitation facilities (safety homes).

- Today, it is possible to detect a cyclone right from its genesis in the high seas and follow its course, giving a warning at least 48 hours prior to a cyclone strike.
- However, the predictions of a storm course made only 12 hours in advance do not have a very high rate of precision.

Questions on Tropical Cyclones from IMD website

What is a Storm Surge?

- Storm Surge is an abnormal rise of sea level as the cyclone crosses the coast.
- Sea water inundates the coastal strip causing loss of life, large scale destruction to property & crop.
- Increased salinity in the soil over affected area makes the land unfit for agricultural use for two or three seasons.
- Storm surge depends on intensity of the cyclone (Maximum winds and lowest pressure associated with it and Coastal bathymetry (shallower coastline generates surges of greater heights).



What is storm tide?

- The storm tide is the combination of **storm surge and the astronomical tide.**

What are the disaster potential of Storm Surge?

- Disaster potential due to cyclones is due to high storm surges occurring at the time of landfall. The storm surges are by far the greatest killers in a cyclone. as sea water inundates low lying areas of the coastal regions causing heavy floods, erosion of beaches and embankments, damage to vegetation and reducing soil fertility.

- Flooding due to storm surges pollute drinking water sources resulting in shortage of drinking water and causing out-break of epidemics, mostly water borne diseases Very strong winds (Gales) may cause uprooting of trees, damage to dwellings, overhead installations, communication lines etc., resulting in loss of life and property.
- Past records show that very heavy loss of life due to tropical cyclones have occurred in the coastal areas surrounding the Bay of Bengal. Cyclones are also often accompanied by very intense & heavy precipitation (exceeding 40-50 cm in a day or about 10cm or more per hour in some places)

Why do 'tropical cyclones' winds rotate counter-clockwise (clockwise) in the Northern (Southern) Hemisphere?

- As the earth's rotation sets up an apparent force (called the Coriolis force) that pulls the winds to the right in the Northern Hemisphere (and to the left in the Southern Hemisphere).
- So, when a low pressure starts to form over north of the equator, the surface winds will flow inward trying to fill in the low and will be deflected to the right and a counter-clockwise rotation will be initiated. The opposite (a deflection to the left and a clockwise rotation) will occur south of the equator.
- This Coriolis force is too tiny to effect rotation in, for example, water that is going down the drains of sinks and toilets.
- The rotation in those will be determined by the geometry of the container and the original motion of the water.
- Thus, one can find both clockwise and counter-clockwise flowing drains no matter what hemisphere you are located. If you don't believe this, test it out for yourself.

Why there are fewer cyclones over the Arabian Sea as compared to the Bay of Bengal?

- Cyclones that form over the Bay of Bengal are either those develop insitu over southeast Bay of Bengal and adjoining Andaman Sea or remnants of typhoons over Northwest Pacific and move across south China sea to Indian Seas.
- As the frequency of typhoons over Northwest Pacific is quite high (about **35 %** of the global annual average), the Bay of Bengal also gets its increased quota.
- The cyclones over the Arabian Sea either originate insitu over southeast Arabian Sea (which includes Lakshadweep area also) or remnants of cyclones from the Bay of Bengal that move across south peninsula. As the majority of Cyclones over the Bay of Bengal weaken over land after landfall, the frequency of migration into Arabian Sea is low.
- In addition to all the above the Arabian Sea is **relatively colder (mosnsoon winds)** than Bay of Bengal and hence inhibits the formation and intensification of the system.

Why there are very few Tropical Cyclones during southwest monsoon season?

- The southwest monsoon is characterized by the presence of strong westerly winds in the lower troposphere (below 5 km) and very strong easterly winds in the upper troposphere (above 9 km). This results **in large vertical wind shear**. Strong vertical wind shear inhibits cyclone development.
- Also the potential zone for the development of cyclones shifts to North Bay of Bengal during southwest monsoon season.
- During this season, the low pressure system upto the intensity of depressions form along the monsoon trough (ITCZ), which extends from northwest India to the north Bay of Bengal.
- The Depression forming over this area crosses Orissa – West Bengal coast in a day or two. These systems have shorter oceanic stay (they make landfall very quickly) which is also one of the reasons

for their non-intensification into intense cyclones.

What are the causes of disaster during cyclone?

- The dangers associated with cyclonic storms are generally three fold.

1. **Floods**
2. **Winds**
3. **Storm Surge**

Very heavy rains causing floods.

- The rainfall associated with a storm vary from storm to storm even with the same intensity. Record rainfall in a cyclonic storm has been as low as trace to as high as 250 cms. It has been found that the intensity of rainfall is about 85 cms/day within a radius of 50 kms and about 35 cms/day between 50 to 100 kms from the centre of the storm. Precipitation of about 50 cm/day is quite common with a C.S. This phenomenal rain can cause flash flood.

Strong wind.

- The strong wind speed associated with a cyclonic storm. (60-90 kmph) can result into some damage to kutcha houses and tree branches likely to break off. Winds of a severe Cyclonic storm (90-120 kmph) can cause uprooting of trees, damage to pucca houses and disruption of communications. The wind associated with a very severe Cyclonic storm and super cyclonic storm can uproot big trees, cause wide spread damages to houses and installations and total disruption of communications. The maximum wind speed associated with a very severe Cyclonic storm that hit Indian coast in the past 100 years was 260 kmph in Oct., 1999 (Paradeep Super cyclone).

Storm surge

- Storm surge occur in places where a tropical cyclone crosses the coast (makes **landfall**).
- The severest destructive feature of a tropical storm is the storm surge popularly called **tidal waves.**
- The costal areas are subjected to storm surge and is accentuated if the landfall time **coincides with that of high tides.** This is again more if the **sea bed is shallow**.
- Storm surge as high as 15 to 20 ft. may occur when all the factors contributing to storm surge are maximum. This storm tide inundates low lying coastal areas which has far reaching consequences apart from flooding.
- **The fertility of land is lost** due to **inundation by saline water** for a few years to come.

Mains 2013: Naming of Cyclones

The recent cyclone on east coast of India was called 'Phailin'. How are the tropical cyclones named across the world? Elaborate.

- WMO (World meteorological organization) divided the world Oceans into Basins and assigned the responsibility of naming the Cyclones to the respective regional bodies.
- Each regional body has its own rules in naming cyclones. In most regions pre-determined alphabetic lists of alternating male and female names are used.
- In the north-west Pacific the majority of names used are not personal names. While there are a few male and female names, majority are names of flowers, animals, birds, trees, foods or descriptive adjectives.

How are cyclones named in Northern Indian Ocean Region

- The names of cyclones in Indian Seas are not allocated in alphabetical order, but are arranged by the name of the country which contributed the name.
- It is usual practice for a storm to be named when it reaches tropical storm strength (winds of **34 knots**).

Knot

The knot (pronounced not) is a unit of speed equal to one nautical mile (1.852 km) per hour, approximately 1.151 mph
Worldwide, the knot is used in meteorology, and in maritime and air navigation—for example, a vessel travelling at 1 knot along a meridian travels approximately one minute of geographic latitude in one hour.
1 international knot = 1 nautical mile per hour (exactly) = 1.852 kilometres per hour (exactly) = 0.514 metres per second (approximately)

- The Indian Meteorological Department (IMD) which issues cyclone advisors to eight countries has a list of names contributed by each of them.
- Every time a cyclone occurs, a name is picked in the order of the names that are already submitted.
- Each country gets a chance to name a cyclone. After all the countries get their turn, the next list of names is followed.

Contributed by	Name			
Bangladesh	Helen	Chapala	Ockhi	Fani
India	**Lehar(2013)**	**Megh**	**Sagar**	**Vayu**
Maldives	Madi	Roanu	Mekunu	Hikaa
Myanmar	Na-nauk	Kyant	Daye	Kyarr
Oman	**Hudhud**	Nada	Luban	Maha
Pakistan	**Nilofar**	Vardah	Titli	Bulbul
Sri Lanka	Priya	Asiri	Gigum	Soba
Thailand	Komen	Mora	Phethai	Amphan

Why is this system of uniformity in naming a cyclone in the region

- Tropical cyclones are named to provide ease of communication between forecasters and the general public regarding forecasts and warnings.
- Since the storms can often last a week or even longer and more than one cyclone can be occurring in the same region at the same time, names can reduce the confusion about what storm is being described
- Naming them after a person/flower/animal etc. makes it easier for the media to report on tropical cyclones, increases community preparedness, also helps in quick information exchange between faraway stations, ships etc.

Polar or Arctic Cyclones

- Arctic or polar cyclones occur in Antarctic regions and can reach up to 1,200 miles wide.
- Polar cyclones differ with others because they are not seasonal. **[Tropical Cyclones are seasonal]**
- They can occur at any time of the year.
- Polar cyclones **can also form quickly (sometimes less than 24 hours)**, and their direction or movement **cannot be predicted**.
- They can last from a **day up to several weeks**. [Tropical Cyclones doesn't for more than a week]
- Most frequently, polar cyclones develop above northern Russia and Siberia.

Maximum Sustained Wind

- India Meteorological Department (IMD) uses a 3 minutes averaging for the sustained wind.
- Maximum sustained wind is the highest 3 minutes surface wind occurring within the circulation of the system.

Low Pressure, Depression and Cyclone

How are low pressure system classified in India? What are the differences between low, depression and cyclone?

- The pressure criteria is used, when the system is over land and wind criteria is used, when the system is over the sea.
- The system is called as low if there is one closed isobar in the interval of 2 hPa.
- It is called depression, if there are two closed isobars, a deep depression, if there are three closed isobars and cyclonic

storm if there are four or more closed isobars.

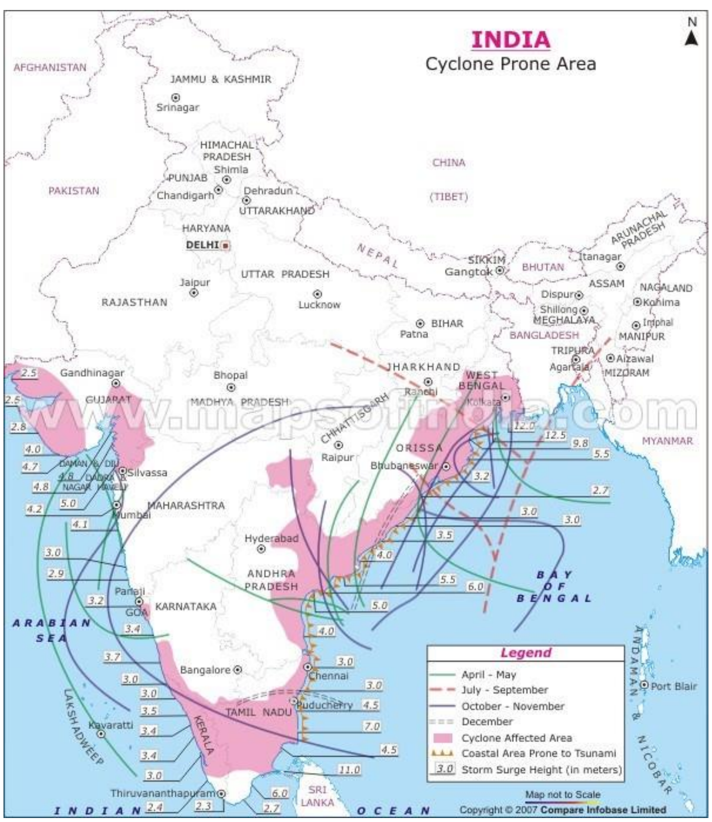
- The detailed classification based on wind criteria are given in the Table below.

System	Pressure deficient hPa	Wind speed Knots (Kmph)
Low pressure area	1.0	<17(<32)
Depression	1.0- 3.0	17-27 (32–50)
Deep Depression	3.0 - 4.5	28-33 (51–59)
Cyclonic Storm	4.5- 8.5	34-47 (60-90)
Severe Cyclonic Storm (SCS)	8.5-15.5	48-63 (90-119)
Very Severe Cyclonic Storm	15.5-65.6	64-119 (119-220)
Super Cyclonic Storm	>65.6	>119(>220)

Central Dense Overcast (CDO)

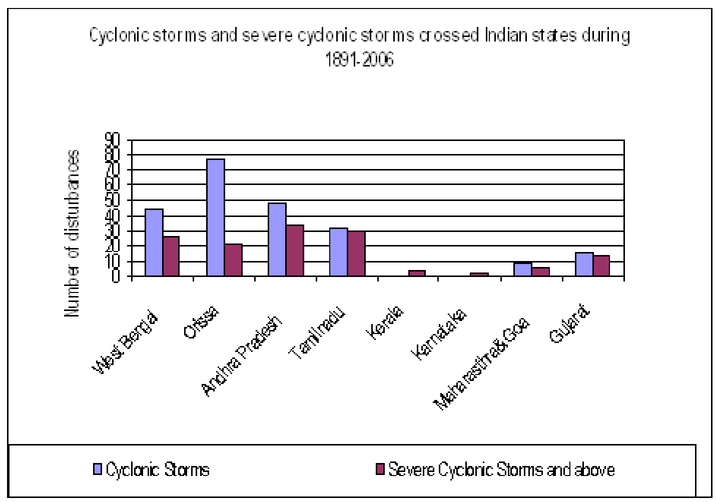
- "CDO" is an acronym that stands for "**central dense overcast**".
- This is the **cirrus cloud shield** that results from the thunderstorms in the eyewall of a tropical cyclone and its rainbands.
- **Before the tropical cyclone reaches very severe cyclonic storm (64 knots,), typically the CDO is uniformly showing the cold cloud tops of the cirrus with no eye apparent.**

Annual frequency of Cyclones over the Indian Seas



- The average annual frequency of tropical cyclones in the north Indian Ocean (Bay of Bengal and Arabian Sea) is about 5 (about **5-6 % of the Global annual average**) and about 80 cyclones form around the globe in a year.
- The frequency is more in the Bay of Bengal than in the Arabian Sea, the ratio being **4:1.**

States Vulnerable to Cyclones



Which sector of the cyclone experiences strongest winds?

- In general, the strongest winds in a cyclone are found on the right side of the storm. The "right side of the storm" is defined with respect to the storm's motion: if the cyclone is moving to the west, the right side would be to the north of the storm; if the cyclone is moving to the north, the right side would be to the east of the storm, etc.
- The strongest wind on the right side of the storm is mainly due to the fact that the

motion of the cyclone also contributes to its swirling winds.

- A cyclone with a 145 kmph winds while stationary would have winds up to 160 kmph on the right side and only 130 kmph on the left side if it began moving (any direction) at 16 kmph.

What is the normal movement of a Tropical Cyclone?

- The cyclones, which cross 20° N latitude generally, recurve and they are more destructive.
- Tropical Cyclones move as a whole. They casually move west-northwestwards or northwestwards in the northern hemisphere.
- The average speed is 15-20 kmph (360-480 km per day). They may change their direction of movement towards north. During this change their speed of movement decreases to 10 kmph or even less.
- A larger fraction of such storms later turn towards northeast and move northeastwards very fast at a speed of 25 kmph or more.

What is the role of upper tropospheric westerly trough ?

- An Upper tropospheric westerly trough is important for tropical cyclone forecasting as they can force large amounts of vertical wind shear over tropical disturbances and tropical cyclones which may inhibit their strengthening.
- There are also suggestions that these troughs can assist tropical cyclone genesis and intensification by providing additional forced ascent near the storm centre and/or by allowing for an efficient outflow channel in the upper troposphere.
- The location of this trough and its intensity can also influence the movement of the storm and hence can be used for **cyclone track forecasting.**

What is 4-stage warning system for Tropical Cyclones?

IMD and Cyclone Diasster Management

- 1999, IMD introduced a 4-Stage warning system to issue cyclone warnings to the disaster managers. They are as follows:

Pre-Cyclone Watch

- Issued when a depression forms over the Bay of Bengal irrespective of its distance from the coast and is likely to affect Indian coast in future. The pre-cyclone watch is issued by the name of Director General of Meteorology and is issued at least 72 hours in advance of the commencement of adverse weather. It is issued at least once a day.

Cyclone Alert

- Issued atleast 48 hours before the commencement of the bad weather when the cyclone is located beyond 500 Km from the coast. It is issued every three hours.

Cyclone Warning

- Issued at least 24 hours before the commencement of the bad weather when the cyclone is located within 500 Km from the coast. Information about time /place of landfall are indicated in the bulletin. Confidence in estimation increases as the cyclone comes closer to the coast

Post landfall outlook

- It is issued 12 hours before the cyclone landfall, when the cyclone is located within 200 Km from the coast. More accurate & specific information about time /place of landfall and associated bad weather indicated in the bulletin. In addition, the interior distraction is likely to be affected due to the cyclone are warned in this bulletin.

Modifying cyclones?

- Seeding with silver iodide.
- Placing a substance on the ocean surface.
- By nuking them.

- By cooling the surface waters with deep ocean water.
- By adding a water absorbing substance.

How are Tropical Cyclones monitored by IMD?

- A good network of meteorological observatories (both surface and upper air) is operated by IMD, covering the entire coastline and islands.
- The conventional observations are supplemented by observational data from automatic weather stations (AWS), radar and satellite systems.
- INSAT imagery obtained at hourly intervals during cyclone situations has proved to be immensely useful in monitoring the development and movement of cyclones.

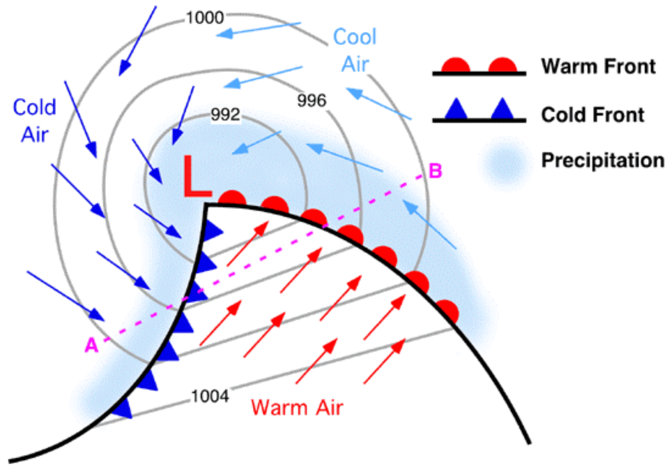
Temperate Cyclones or Extra Tropical Cyclones or Mid-Latitude Cyclones or Frontal Cyclones

- The systems developing in the mid and high latitude **(35° latitude and 65° latitude in both hemispheres)**, beyond the tropics are called the **middle latitude cyclones or extra tropical cyclones or temperate cyclones or frontal cyclones or wave cyclones**.

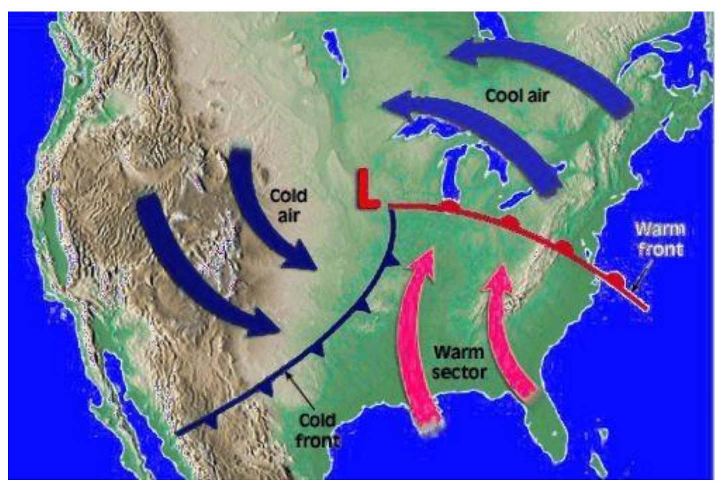
Origin and Development of Temperate Cyclones

Polar Front Theory

- According to this theory, the warm-humid air masses from the tropics meet the dry-cold air masses from the poles and thus a polar front is formed as a surface of discontinuity.
- Such conditions occur over **sub-tropical high, sub-polar low pressure belts** and along the **Tropopause**.



- The cold air pushes the warm air upwards from underneath. Thus a void is created because of lessening of pressure. The surrounding air rushed in to occupy this void and coupled with the earth's rotation, a cyclone is formed which **advances with the westerlies (Jet Streams).**

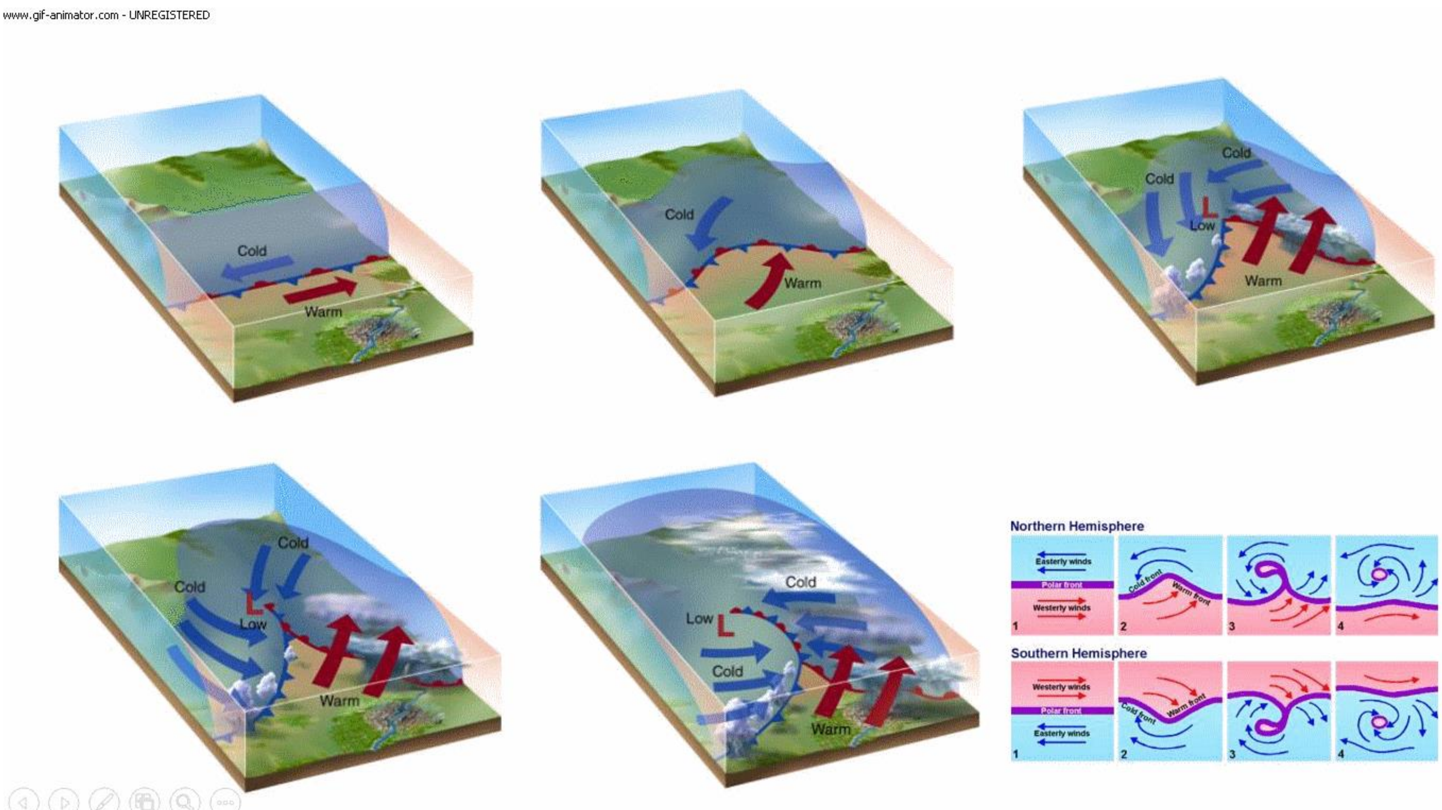


In detail

- In the northern hemisphere, warm air blows from the south and cold air from the north of the front.
- When the pressure drops along the front, the warm air moves northwards and the cold air move towards south setting in

motion an **anticlockwise cyclonic circulation (northern hemisphere). This is due to Coriolis Force.**

- The cyclonic circulation leads to a well-developed extra tropical cyclone, with a warm front and a cold front.
- There are pockets of warm air or warm sector wedged between the forward and the rear cold air or cold sector. The warm air glides over the cold air and a sequence of clouds appear over the sky ahead of the warm front and cause precipitation.
- The cold front approaches the warm air from behind and pushes the warm air up. As a result, cumulus clouds develop along the cold front. The **cold front moves faster** than the warm front ultimately overtaking the warm front. The warm air is completely lifted up and the front is **occluded (occluded front)** and the cyclone dissipates.
- The processes of wind circulation both at the surface and aloft are closely interlinked.
- So temperate cyclone is intense **frontogenesis** involving mainly **occlusion type front**. (Occluded front explained in detail in previous posts).



Gif Image: View in MS power point in Full Screen mode. [The copy of this image is present on my website www.pmfias.com]

- Normally, individual frontal cyclones exist for about 3 to 10 days moving in a generally **west to east direction**.
- Precise movement of this weather system is controlled by the orientation of the polar jet stream in the upper troposphere.

Seasonal Occurrence of Temperate Cyclones

- The temperate cyclones occur mostly in **winter, late autumn and spring**. They are generally associated with rainstorms and cloudy weather.
- During summer, all the paths of temperate cyclones shift northwards and there are only few temperate cyclone over sub-tropics and the warm temperate zone, although a high concentration of storms occurs over Bering Strait, USA and Russian Arctic and sub-Arctic zone.

Distribution of Temperate Cyclones

- USA and Canada – extend over Sierra Nevada, Colorado, Eastern Canadian Rockies and the Great Lakes region,
- the belt extending from Iceland to Barents Sea and continuing over Russia and Siberia,
- winter storms over Baltic Sea,
- Mediterranean basin extending up to Russia and even up to India in winters (called western disturbances) and the Antarctic frontal zone.

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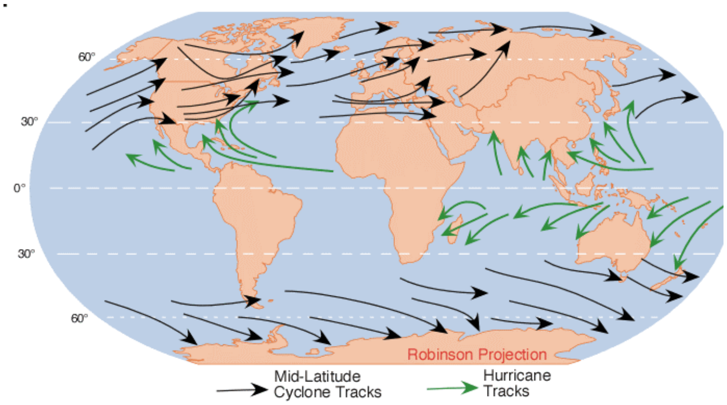
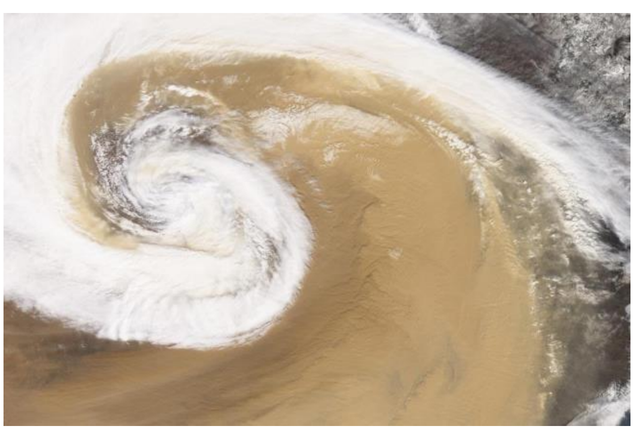


Characteristics of Temperate Cyclones

Size and Shape

- The temperate cyclones are asymmetrical and shaped like an inverted 'V'.
- They stretch over 500 to 600 km.
- They may spread over 2500 km over North America (**Polar Vortex**).
- They have a height of 8 to 11 km.

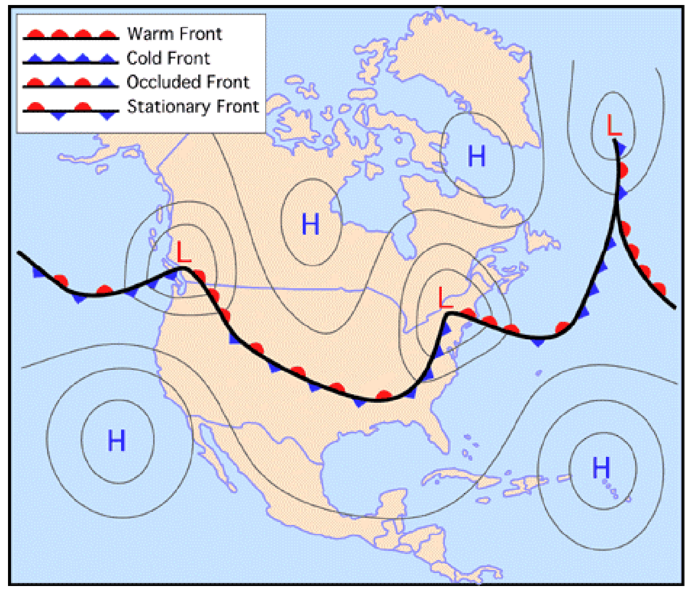


Wind Velocity And Strength

- The wind strength is more in eastern and southern portions, more over North America compared to Europe.
- The wind velocity increases with the approach but decreases after the cyclone has passed.

Orientation And Movement

- Jet stream plays a major role in temperate cyclonogeneis.
- Jet streams also influence the path of temperate cyclones.



- Since these cyclones move with the **westerlies (Jet Streams)**, they are oriented **east-west**.
- If the storm front is east-west, the center moves swiftly eastwards.
- If the storm front is directed northwards, the center moves towards the north, but after two or three days, the pressure difference declines and the cyclone dissipates.
- In case the storm front is directed southwards, the center moves quite deep southwards-even up to the Mediterranean region [sometimes causing the Mediterranean cyclones or **Western Disturbances** (They are very important as they bring rains to North-West India – Punjab, Haryana)].

Structure

- The north-western sector is the cold sector and the north-eastern sector is the warm sector (Because cold air masses in north and warm air masses in south push against each other and rotate anti-clockwise in northern hemisphere).

Associated Weather

- The approach of a temperate cyclone is marked by fall in temperature, fall in the mercury level, wind shifts and a **halo around the sun and the moon**, and a thin veil of **cirrus clouds.**
- A light drizzle follows which turns into a heavy downpour. These conditions change with the arrival of the warm front which halts the fall in mercury level and the rising temperature.
- Rainfall stops and clear weather prevails until the cold front of an anticyclonic character arrives which causes a fall in temperature, brings cloudiness and rainfall with thunder. After this, once again clear weather is established.
- The temperate cyclones experience more rainfall when there is slower movement and a marked difference in rainfall and temperature between the front and rear of the cyclone. These cyclones are generally accompanied by anticyclones.

Tropical Cyclones and Temperate Cyclones Comparison

	Tropical Cyclone	Temperate Cyclone
Origin	**Thermal Origin**	**Dynamic Origin** – Coriolis Force, Movement of air masses.
Latitude	Confined to 10^0 - 30^0 N and S of equator.	Confined to 35^0 - 65^0 N and S of equator. More pronounced in Northern hemisphere due to **greater temperature contrast**.
Frontal system	Absent	The very cyclone formation is due to frontogenesis.[Occluded Front]
Formation	They form only on seas with temperature more than 26-27^0 C. They dissipate on reaching the land.	Can form **both** on land as well as seas
Season	Seasonal: Late summers (Aug - Oct)	Irregular. But few in summers and **more in winters**.
Size	Limited to small area. Typical size: 100 – 500 kms in diameter. Varies with the strength of the cyclone.	They cover a larger area. Typical size: 300 – 2000 kms in diameter. Varies from region to region.
Shape	Elliptical	Inverted 'V'
Rainfall	Heavy but does not last beyond a few hours. If the cyclone stays at a place, the rainfall may continue for many days.	In a temperate cyclone, rainfall is slow and continues for many days, sometimes even weeks.
Wind Velocity and destruction	Much greater (100 – 250 kmph)(200 – 1200 kmph in upper troposphere) Greater destruction due to **winds, storm surges and torrential rains.**	Comparatively low. Typical range: 30 – 150 kmph. Less destruction due to winds but more destruction due to **flooding.**
Isobars	Complete circles and the **pressure gradient is steep**	Isobars are usually 'V' shaped and the pressure gradient is low.
Life time	Doesn't last for more than a week	Last for 2-3 weeks.

Path	East – West. Turn North at 20^0 latitude and west at 30^0 latitude. Move away from equator. The movement of Cyclones in Arabian Sea and Bay of Bengal is a little different. Here, these storms are superimposed upon the **monsoon circulation** of the summer months, and they move in northerly direction along with the monsoon currents.	West – East (Westerlies – Jet Streams). Move away from equator.
Temperature distribution	The temperature at the center is almost equally distributed.	All the sectors of the cyclone have different temperatures
Calm region	The center of a tropical cyclone is known as the eye. The wind is calm at the center with no rainfall.	In a temperate cyclone, there is not a single place where winds and rains are inactive.
Driving force	The tropical cyclone derives its energy from the **latent heat of condensation**, and the difference in densities of the air masses does not contribute to the energy of the cyclone.	The energy of a temperate cyclone depends on the **densities of air masses**.
Influence of Jet streams	The relationship between tropical cyclones and the upper level air-flow is not very clear.	The temperate cyclones, in contrast, have a distinct relationship with upper level air flow (jet streams, Rossby waves etc.)
Clouds	The tropical cyclones exhibit fewer varieties of clouds – cumulonimbus, nimbostratus, etc..	The temperate cyclones show a variety of cloud development at various elevations.
Surface anti-cyclones	The tropical cyclones are not associated with surface anticyclones and they have a greater destructive capacity.	The temperate cyclones are associated with anticyclones which precede and succeed a cyclone. These cyclones are not very destructive.
Influence on India	Both coasts effected. But east coast is the hot spot.	Bring rains to North – West India. The associated instability is called '**Western Disturbances**'.

- Titbit: In certain instances, two cyclones move toward each other and revolve around one another, with the smaller and less intense one moving more quickly. This phenomenon is called the **Fujlwara effect**.

Questions

Multiple choice questions

- The direction of wind around a low pressure in northern hemisphere is: (a) clockwise (c) anti-clock wise (b) perpendicular to isobars (d) parallel to isobars

150 words

- Why does tropical cyclone originate over the seas? In which part of the tropical cyclone do torrential rains and high velocity winds blow and why?

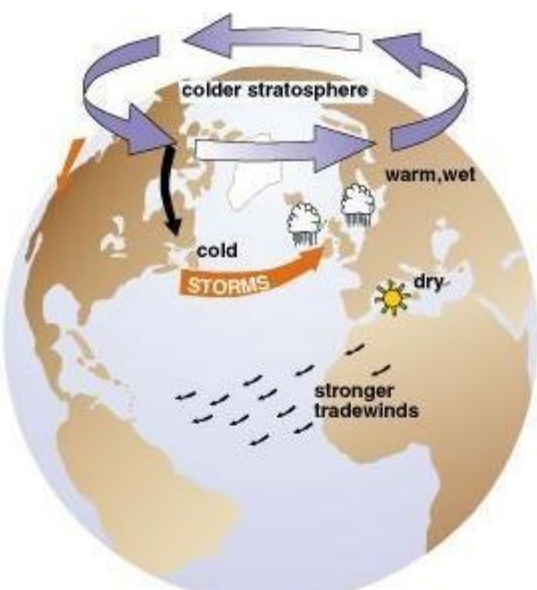
In this post: Polar Vortex – Ozone Depletion – Polar Stratospheric Clouds.

Polar Vortex

- In the previous posts, we have studied about tropical cyclones and extra tropical cyclones (Temperate Cyclone). Here we will study Polar vortex (circumpolar vortex) which is a **polar cyclone.**
- A polar vortex is a large pocket of very cold air, typically the coldest air in the Northern Hemisphere, which sits over the polar region during the winter season.
- Polar Vortex is a

1. *Cold;*
2. *Upper tropospheric: sometime extending till the lower levels of **stratosphere** (At poles, the troposphere extends up to 8-9 km);*
3. *Circumpolar;*
4. *Low pressure;*
5. *Large cyclonic parcel of air [1000 km] (counter-clockwise in the Northern Hemisphere)*

- Polar vortex is closely associated with **jet streams [Rossby waves].**
- It is formed mainly in winter and gets **weaker in summer**.
- It surrounds **polar highs** and lie within the polar front (boundary separating the temperate and polar air masses).



Polar Vortex Cold Wave

How Polar Vortex slips towards Midlatitudes,

Breakdown of the polar vortex,

Sudden stratospheric warming,

Polar vortex event.

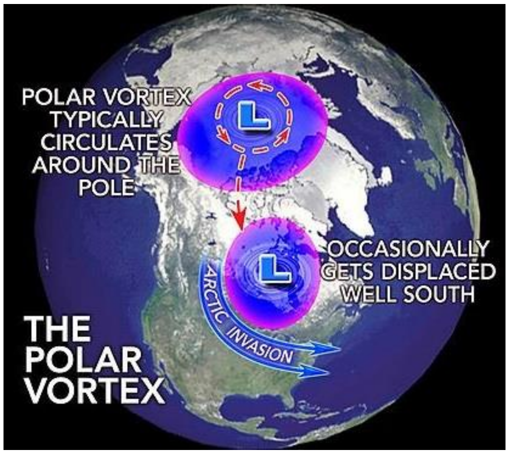
All the above phrases mean the same – Polar Vortex Cold Wave.

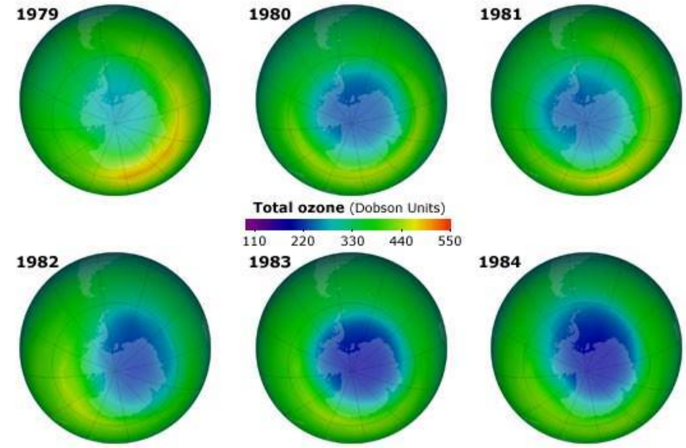
- The polar vortex will remain in its place when the Westerlies along with the polar jet are strong (Strong polar vortex means there is **huge temperature contrast** between the temperate and polar regions).
- When the polar vortex is weak, it intrudes into the midlatitude regions by buckling the general wind flow pattern. This leads to significant cold outbreaks in the midlatitude regions.
- The vortex is capable of delivering subzero temperatures to the United States and Canada where is occurs the most.

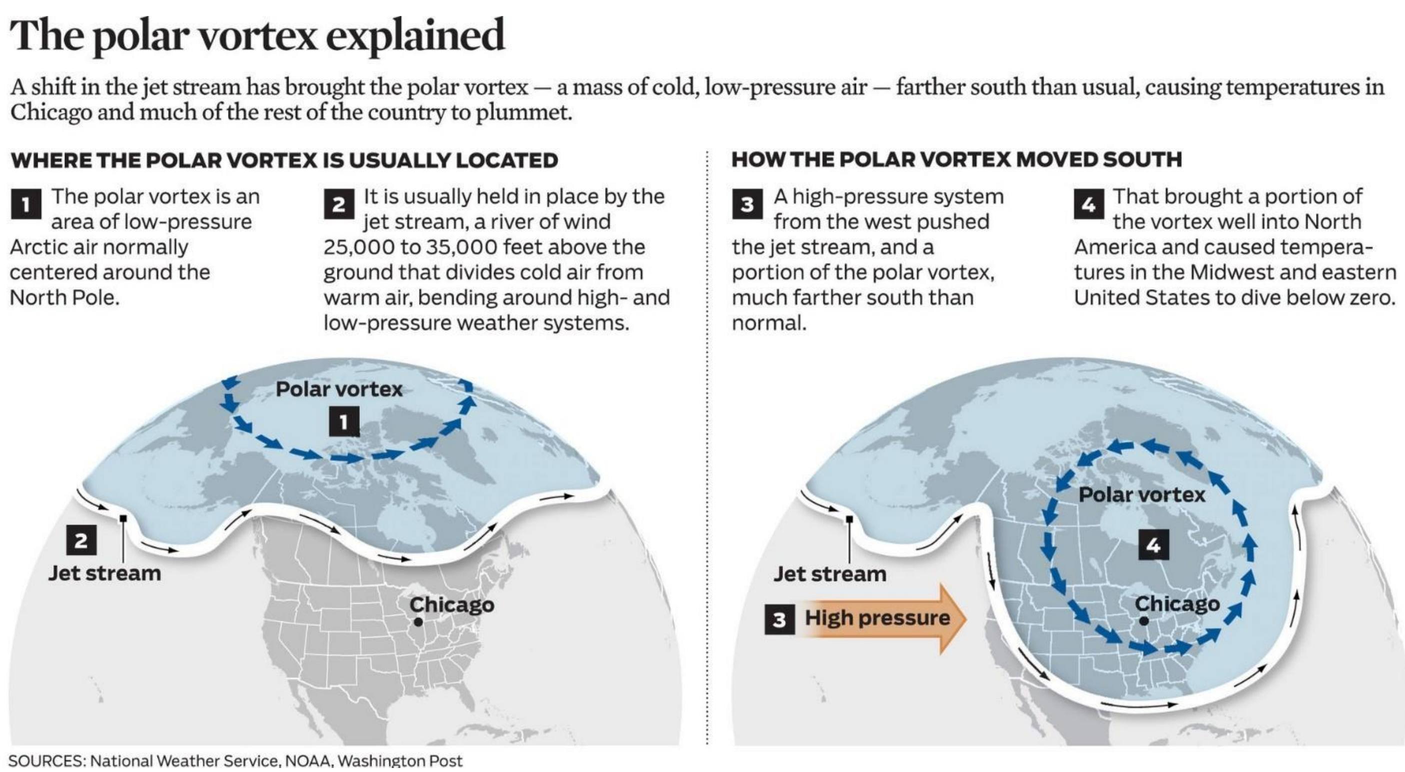
How it slips

- The Polar jet traverses somewhere over 65^0 N and S latitudes. When the temperature contrast between polar and temperate regions is maximum, the jet is very strong and the meandering is negligible.
- But when the temperature contrast is low (doesn't mean it's summer), the jet starts to meander (Rossby waves).
- Meandering jet creates alternating low and high pressure cells. High pressure cells are created below the ridges and the low pressure cells below the troughs (This is because of the upper air circulations created by the jet).
- With severe meandering, the high pressure cells push over to north and displace the polar cyclone from its normal position i.e. the cyclone moves away from the pole and slips into the temperate regions where there is an intense low pressure.
- With the strengthening of the jet, the high pressure cells become weak and retreat to

their normal latitudinal positions. With the retreat of the high pressure cells, the polar cyclone moves back to its normal position – poles.







Ozone Hole [Ozone Depletion at South Pole]

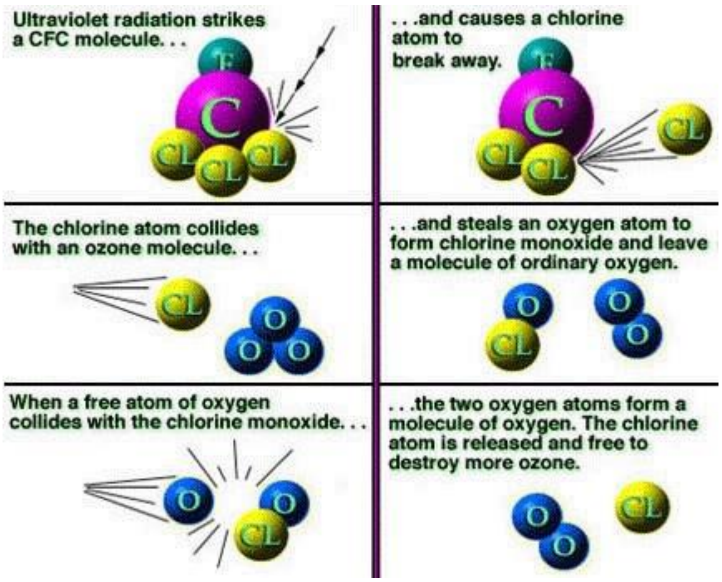
- Polar vortex and ozone depletion are two distinct but related phenomena.
- There is a steady decline of about **4%** in the total volume of ozone in Earth's stratosphere.
- Much larger decrease in stratospheric ozone is observed around **Earth's polar regions.**
- Depletion of ozone is due to increase in **halocarbons** in the atmosphere.

Halocarbon == a compound in which the hydrogen of a hydrocarbon is replaced by halogens like chlorine, bromine, iodine etc.

Halogen == group of reactive non-metallic elements like fluorine, chlorine, bromine, iodine, and astatine.

Halogen atoms like chlorine destroy ozone

- **Photodissociation** (under the influence of sunlight) of **ozone-depleting substances (ODS)** like *halocarbon refrigerants, solvents, propellants, and foam-blowing agents (CFCs, HCFCs, carbon tetrachloride and trichloroethane, freons, halons)* creates **free chlorine atoms** that destroy ozone.



But how does a chlorine atom reach to such high levels of atmosphere?

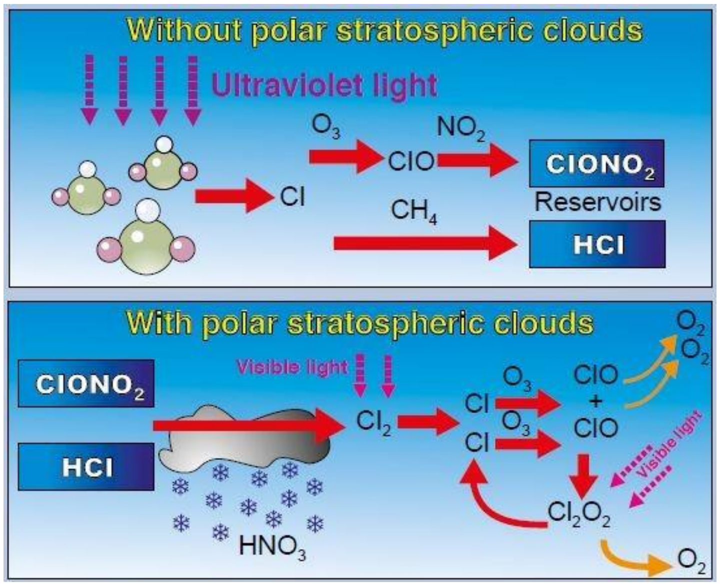
Polar Stratospheric Clouds (PSCs)

- Extend from 12 km – 22 km above the surface.
- They are nacreous clouds.

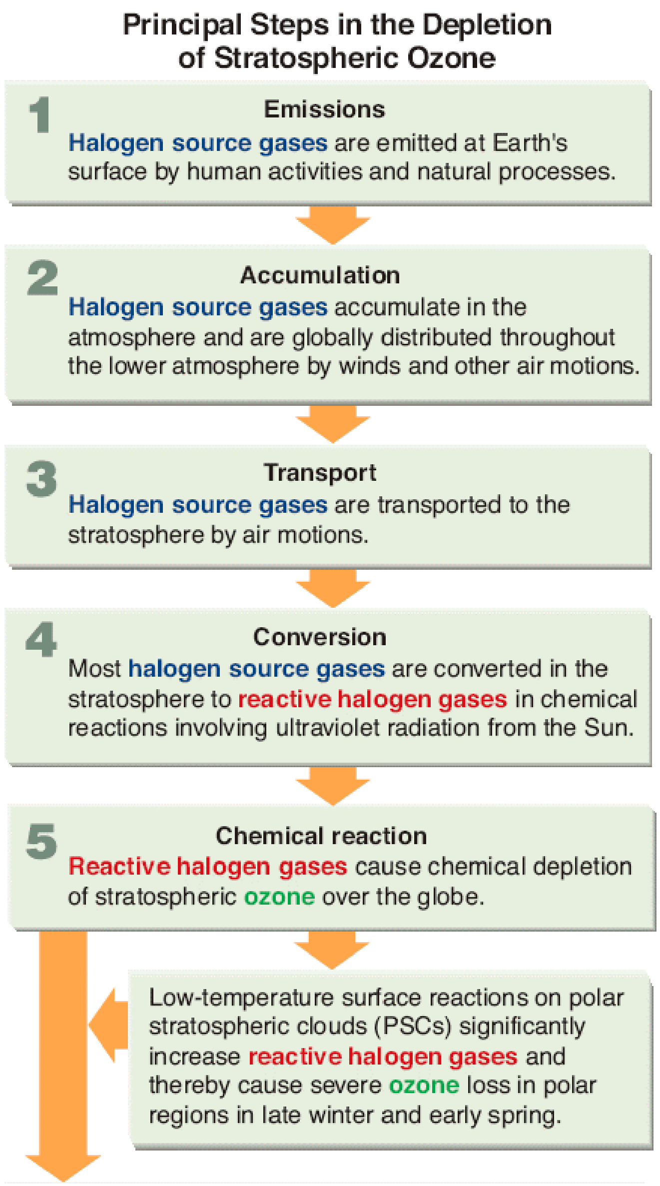
Nacreous clouds

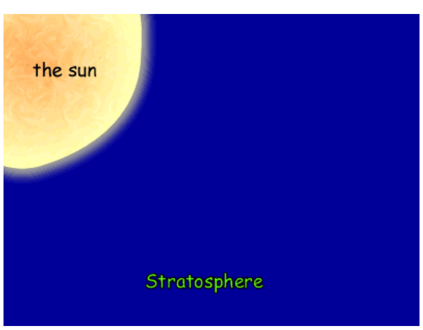
Nacreous clouds, sometimes called mother-of-pearl clouds, are rare clouds.
They are mostly visible within two hours after sunset or before dawn.
They form in frigid regions of the lower stratosphere, some 15 - 25 km (9 -16 mile) high and well above tropospheric clouds.
They are bright even after sunset and before dawn because at those heights there is still sunlight.
They are seen mostly during winter at high latitudes like Scandinavia, Iceland, Alaska and Northern Canada. Sometimes, however, they occur as far south as England.

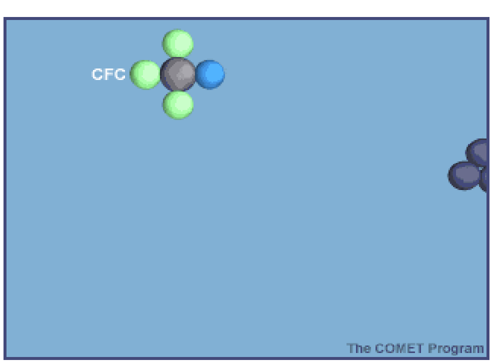
- PSCs or nacreous clouds contain **water, nitric acid and/or sulfuric acid**.
- **They are formed mainly during the event of polar vertex in winter; more intense at south pole.**
- The Cl-catalyzed ozone depletion is dramatically enhanced in the presence of polar stratospheric clouds (PSCs) **[Finally this how polar vortex leads to ozone depletion]**



- PSCs convert "reservoir" compounds into reactive free radicals **(Cl and ClO).**
- These free radicals deplete ozone as shown in the animation below.
- **So PSC accelerate ozone depletion.**







Gif Images

Prelims question: The formation of ozone hole in the Antarctic region has been a cause of concern. What could be the reason for ozone depletion at poles?

a) Presence of prominent tropospheric turbulence; and inflow of chlorofluorocarbons
b) Presence of prominent polar front and stratospheric Clouds and inflow of chlorofluorocarbons
c) Absence of polar front and stratospheric clouds; and inflow of methane and chlorofluorocarbons
d) Increased temperature at polar region due to global warming

In this post: El Nino, El Nino Southern Oscillation ENSO, Indian Ocean Dipole IOD, La Nina and El Nino Modoki.

El Nino

- El Niño is the name given to the occasional development of warm ocean surface waters along the coast of **Ecuador and Peru**.
- When this warming occurs the usual upwelling of cold, nutrient rich deep ocean water is significantly **reduced.**
- El Niño normally occurs around **Christmas** and usually lasts for a few weeks to a few months.
- Sometimes an extremely warm event can develop that lasts for much longer time periods. In the 1990s, strong El Niños developed in 1991 and lasted until 1995, and from fall 1997 to spring 1998.

Normal Conditions

- In a normal year, a surface **low pressure** develops in the region of **northern Australia and Indonesia** and a **high pressure** system over the **coast of Peru**. As a result, the **trade winds** over the Pacific Ocean move strongly from **east to west.**

- The easterly flow of the trade winds carries warm surface waters **westward**, bringing **convective storms (thunderstorms)** to Indonesia and coastal Australia. Along the coast of Peru, cold bottom **cold nutrient rich water wells up** to the surface to replace the warm water that is pulled to the west.

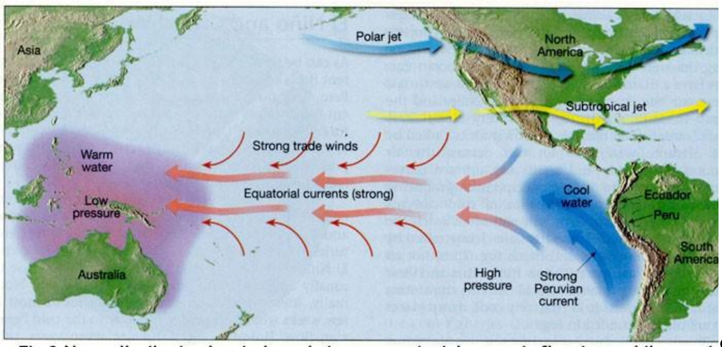
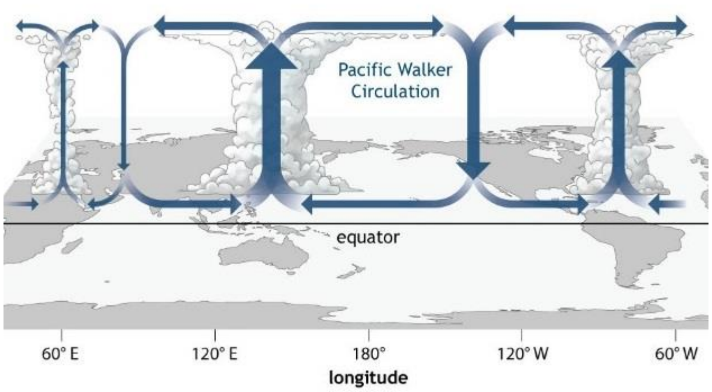


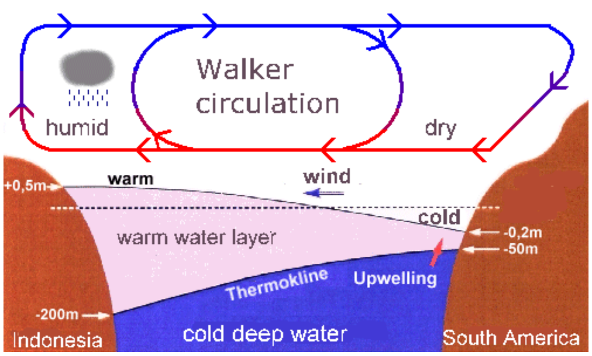
Fig.6 Normally, the trade winds and strong equatorial currents flow toward the west. At the same time, an intense Peruvian current causes upwelling of cold water along the west coast of South America.

Neutral conditions

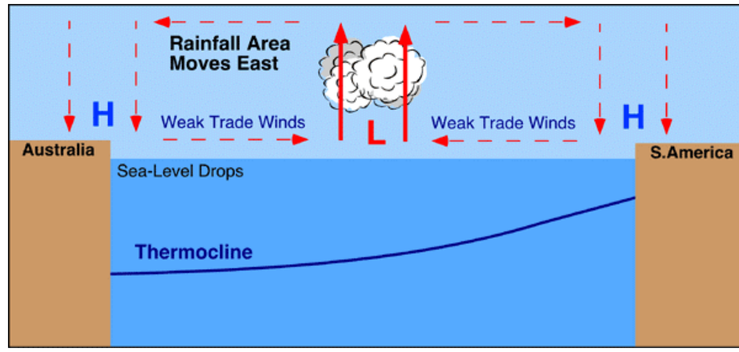


Walker circulation (Occurs during Normal Years)

- The Walker circulation (walker cell) is caused by the pressure gradient force that results from a **high pressure system over the eastern Pacific ocean**, and a **low pressure system over Indonesia.**



Gif Image



This cross-section of the Pacific Ocean, along the equator, illustrates the pattern of atmospheric circulation typically found at the equatorial Pacific. Note the position of the ***thermocline.***

- **Thermocline** == noun a temperature gradient in a lake or other body of water, separating layers at different temperatures.
- The Walker cell is indirectly related to upwelling off the coasts of Peru and Ecuador. This brings nutrient-rich cold water to the surface, increasing **fishing stocks.**

During El Nino year

- In an El Niño year, air pressure drops over large areas of the central Pacific and along the coast of South America.
- The normal low pressure system is replaced by a weak high in the western Pacific (the **southern oscillation**). This change in pressure pattern causes the **trade winds to be reduced == Weak Walker Cell.** Sometimes Walker Cell might even get reversed.
- This reduction allows the **equatorial counter current (current along doldrums)** to accumulate warm ocean water along the coastlines of Peru and Ecuador.

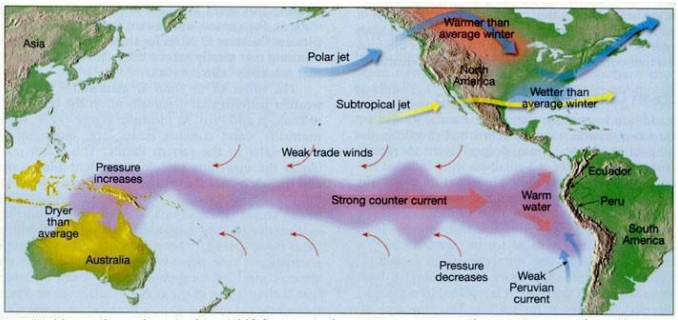
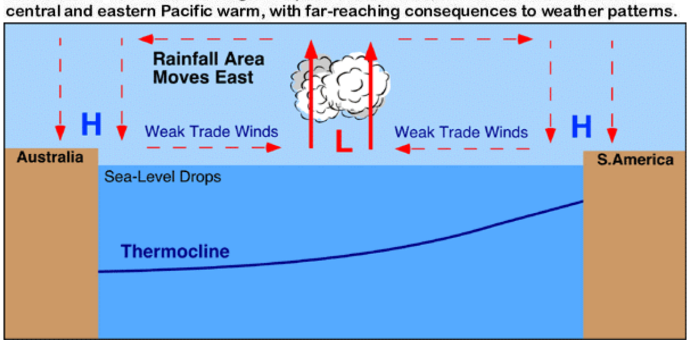
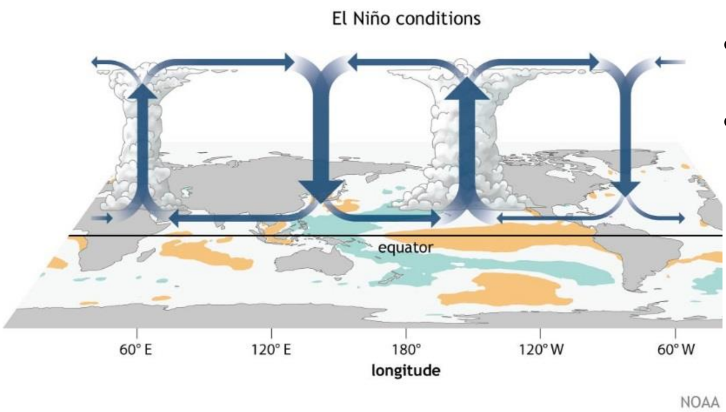


Fig.14 Upon the advent of an ENSO event, the pressure over the eastern and western Pacific flip-flops. This causes the trade winds to diminish, leading to an eastward movement of warm water along the equator. As a result, the surface waters of the central and eastern Pacific warm, with far-reaching consequences to weather patterns.





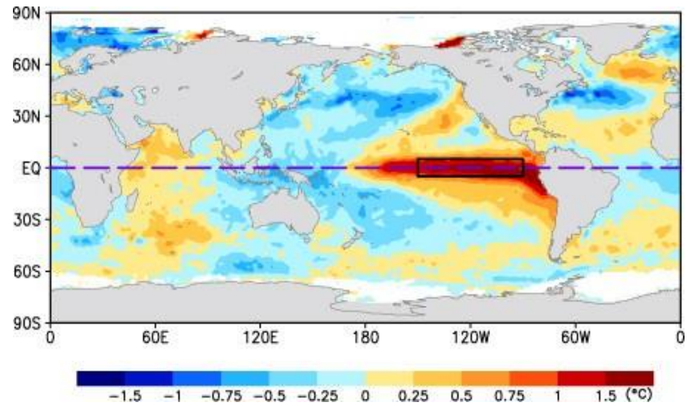
- This accumulation of warm water causes the thermocline to drop in the eastern part of Pacific Ocean which **cuts off the upwelling of cold deep ocean water** along the coast of Peru.
- Climatically, the development of an El Niño brings **drought to the western Pacific**, **rains to the equatorial coast of South America**, and **convective storms and hurricanes to the central Pacific.**

This cross-section of the Pacific Ocean, along the equator, illustrates the pattern of atmospheric circulation that causes the formation of the El Niño.

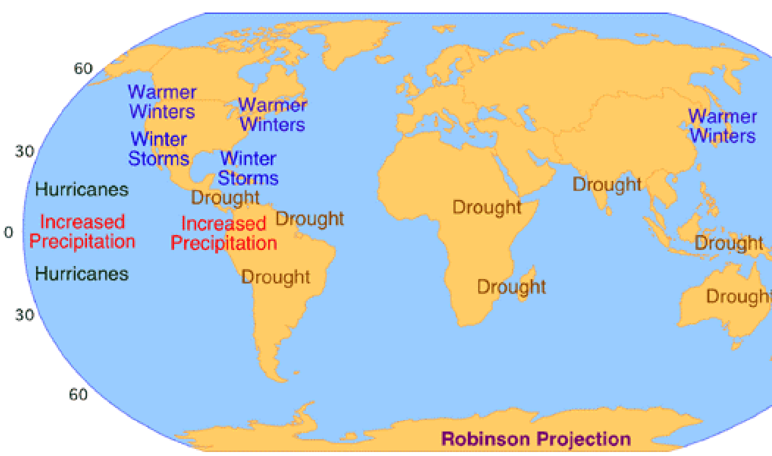
- In the image above, we can see the presence of a strong El Niño event (October, 1997).

Effects of El Nino

- The warmer waters had a **devastating effect on marine life** existing off the coast of Peru and Ecuador.



- Fish catches off the coast of South America were lower than in the normal year (Because there is no upwelling).
- **Severe droughts occur in Australia, Indonesia, India and southern Africa.**
- Heavy rains in California, Ecuador, and the Gulf of Mexico.



Normal Conditions

Eastern Pacific == Coast of Peru and Ecuador == Cold Ocean Water == Good for Fishing.

Western Pacific == Indonesia and Australia == Warm Ocean Water == Plenty of rains.

El Nino Condition

Eastern Pacific == Coast of Peru and Ecuador == Warm Ocean Water == Fishing industry takes a hit.

Western Pacific == Indonesia and Australia == Cold Ocean Water == Drought.

How El Nino impacts monsoon rainfall in India

- El Nino and Indian monsoon are **inversely related**.
- The most prominent droughts in India - six of them - since 1871 have been El Nino droughts, including the recent ones in 2002 and 2009
- However, not all El Nino years led to a drought in India. For instance, 1997/98 was a strong El Nino year but there was no drought (Because of IOD).
- On the other hand, a moderate El Nino in 2002 resulted in one of the worst droughts.
- El Nino directly impacts India's agrarian economy as it tends to lower the production of summer crops such as rice, sugarcane, cotton and oilseeds.
- The ultimate impact is seen in the form of high inflation and low gross domestic product growth as agriculture contributes around 14 per cent to the Indian economy.

El Nino Southern Oscillation [ENSO]

- The formation of an **El Niño [Circulation of Water]** is linked with Pacific Ocean circulation pattern known as the **southern oscillation [circulation of atmospheric pressure]**
- Southern Oscillation, in oceanography and climatology, is a coherent inter-annual **fluctuation of atmospheric pressure** over the tropical Indo-Pacific region.
- El Nino and Southern Oscillation coincide most of the times hence their combination is called **ENSO – El Nino Southern Oscillation.**

Only El Nino == [Warm water in Eastern Pacific + Cold water in Western Pacific].

Only SO == [Low Pressure over Eastern Pacific + High Pressure over Western Pacific]

ENSO = [Warm water in Eastern Pacific + Low Pressure over Eastern Pacific] + [Cold water in Western Pacific + High Pressure over Western Pacific].

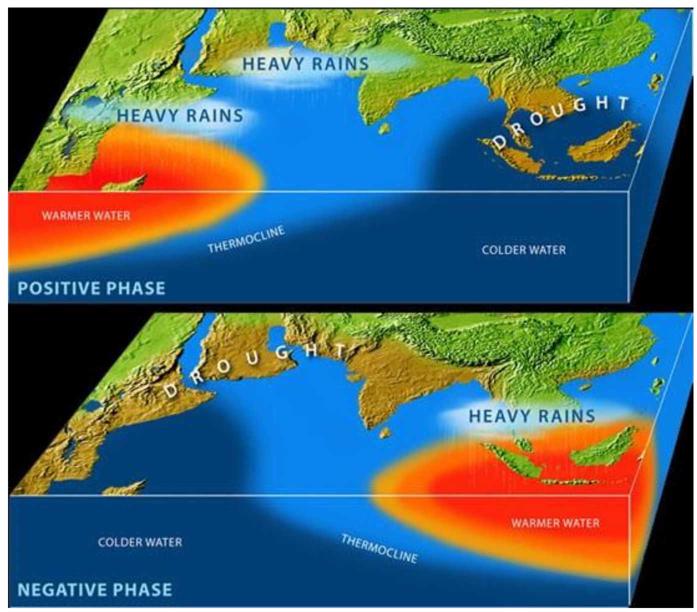
Southern Oscillation Index and Indian Monsoons

- SO is a see-saw pattern of meteorological changes observed between the Eastern Pacific and Western Pacific.
- When the pressure was high over equatorial Eastern Pacific, it was low over the equatorial Western Pacific and vice versa.
- The pattern of low and high pressures gives rise to vertical circulation along the equator with its rising limb over low pressure area and descending limb over high pressure area. This is known as Walker Circulation.
- The location of low pressure and hence the rising limb over Western Pacific is considered to be conductive to good monsoon rainfall in India.
- **Its shifting eastward** from its normal position, such as in El Nino years, reduces monsoon rainfall in India.
- Due to the close association between an El Nino (E.N.) and the Southern Oscillation SO the two are jointly referred to as an **ENSO event.**
- The **periodicity of SO is not fixed and its period varies from two to five years.**
- Southern Oscillation Index (SOD) is used to measure the intensity of the Southern Oscillation.
- This is the difference in pressure between **Tahiti in French Polynesia** (Central Pacific), representing the Central Pacific Ocean and **Port Darwin**, in northern Australia representing the Eastern Pacific Ocean.
- The positive and negative values of the SOI i.e. Tahiti minus the Port Darwin pressure are pointers towards good or bad rainfall in India.

Positive SOI	Negative SOI
Tahiti pressure greater than that of Port Darwin	Reverse
Pressure high over eastern Pacific and low over	Reverse
Drought conditions in Eastern Pacific and good rainfall in Western Pacific (Northern Australia and Indonesia)	Reverse
Good for Indian Monsoons	Bad for Indian Monsoons

Indian Ocean Dipole effect (Not every El Nino year is same in India)

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



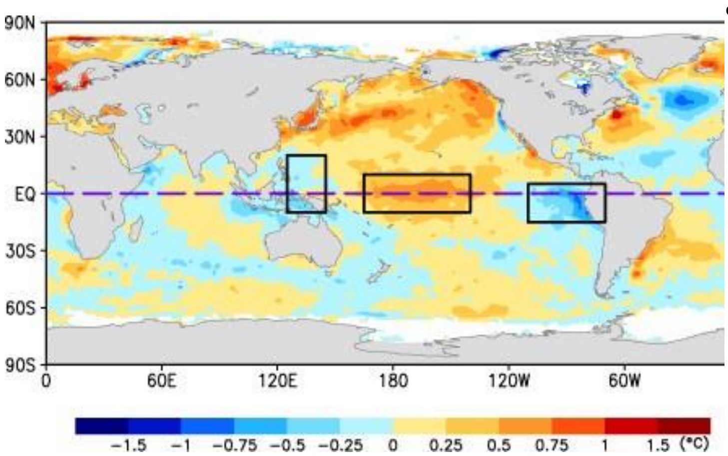
- It was demonstrated that a positive IOD index often negated the effect of ENSO, resulting in increased Monsoon rains in several ENSO years like the 1983, 1994 and 1997.
- Further, it was shown that the two poles of the IOD - the eastern pole (around Indonesia) and the western pole (off the African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

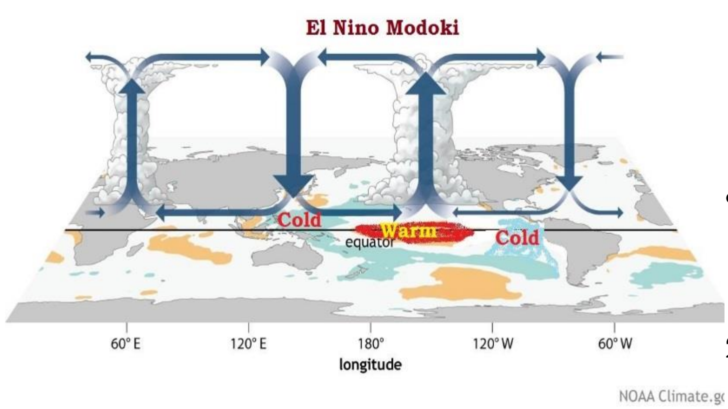
Impact on IOD on Cyclonogeneis in Northern Indian Ocean

- Negative IOD (Arabian Sea warmer than Bay of Bengal) results in more cyclones than usual in Arabian Sea.
- Positive IOD results in stronger than usual cyclonogenesis in Bay of Bengal. Cyclonogenesis in Arabian Sea is suppressed.

The El Niño Modoki

- El Niño Modoki is a coupled ocean-atmosphere phenomenon in the tropical Pacific.
- It is different from another coupled phenomenon in the tropical Pacific namely, El Niño.
- Conventional El Niño is characterized by **strong anomalous warming in the eastern equatorial Pacific**.
- Whereas, El Niño Modoki is associated with **strong anomalous warming in the central tropical Pacific and cooling in the eastern and western tropical Pacific** (see figure below).



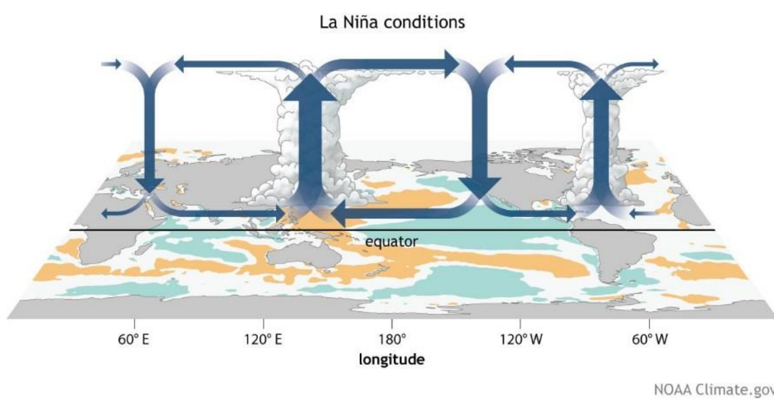


El Niño Modoki Impacts

- The El Niño Modoki phenomenon is characterized by the anomalously warm central equatorial Pacific flanked by anomalously cool regions in both west and east.
- Such zonal gradients result in anomalous **two-cell Walker Circulation** over the tropical Pacific, with a wet region in the central Pacific.

La Nina

- After an El Niño event weather conditions usually return back to normal.
- However, in some years the trade winds can become **extremely strong** and an abnormal accumulation of cold water can occur in the central and eastern Pacific. This event is called a La Niña.
- A strong La Niña occurred in 1988 and scientists believe that it may have been responsible for the summer drought over central North America. During this period, the Atlantic Ocean has seen **very active hurricane seasons** in 1998 and 1999.
- One of the hurricanes that developed, named **Mitch**, was the strongest October hurricane ever to develop in about 100 years of record keeping.

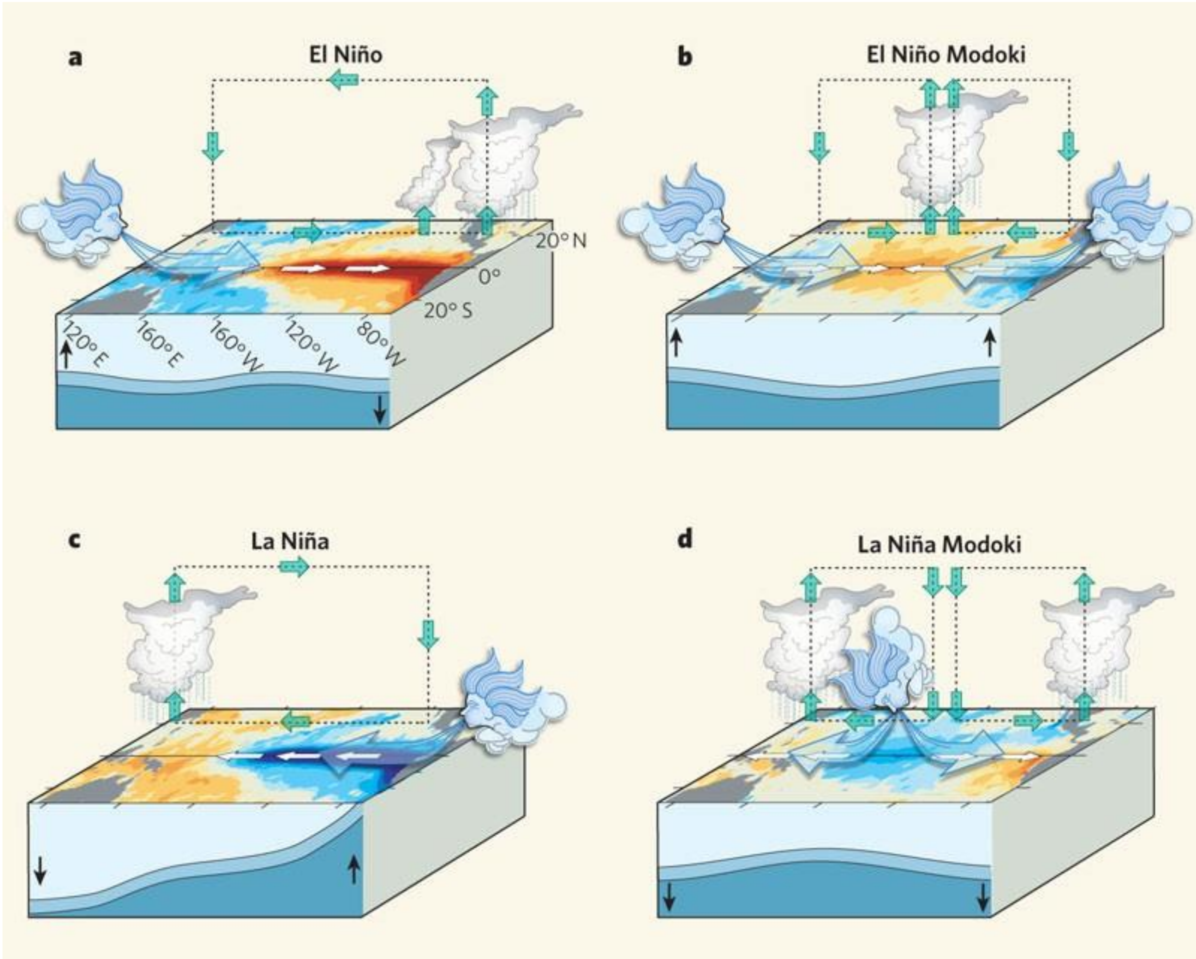


Effects of La Nina

- Some of the other weather effects of La Niña include

1. **abnormally heavy monsoons in India and Southeast Asia**,
2. cool and wet winter weather in southeastern Africa, wet weather in eastern Australia,

3. cold winter in western Canada and northwestern United States,
4. winter drought in the southern United States.



Climatic Regions

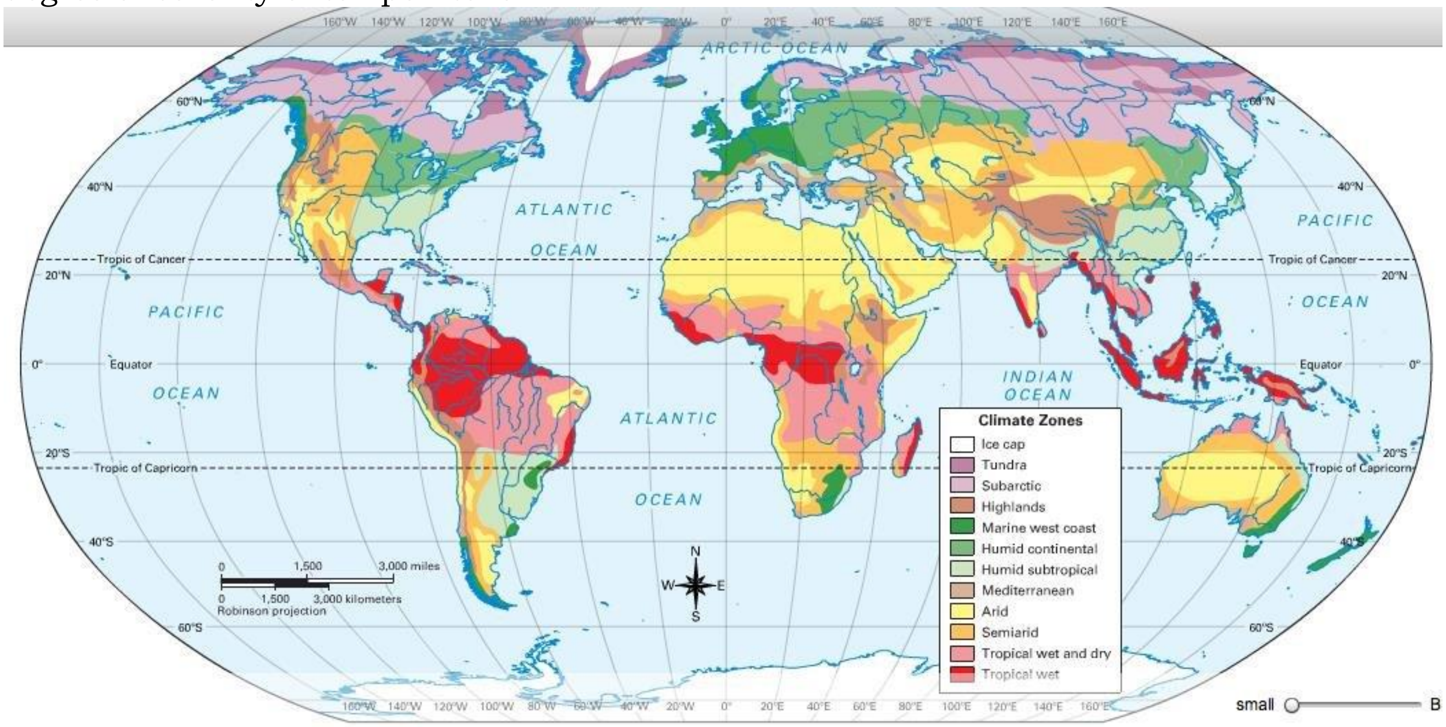
In this post: Koeppen's scheme Of Classification Of Climate - Tropical Humid Climates - Tropical Wet Climate [Hot, Wet Equatorial Climate, Equatorial Rainforest Climate, Equatorial Rainforests, Equatorial Evergreen Forests, Tropical Moist Broadleaf Forest, Lowland Equatorial Evergreen Rainforest]

Koeppen's scheme Of Classification Of Climate

- The most widely used classification of climate is the empirical climate classification scheme developed by V. Koeppen. [**empirical**: verifiable by observation or experience rather than theory or pure logic][when dropped, stone falls to the ground – logic. Drop a stone to confirm that it falls to the ground – empirical]
- Koeppen identified a close relationship between the **distribution of vegetation** and **climate.** He selected certain values of **temperature** and **precipitation** and related them to the **distribution of vegetation** and used these values for classifying the climates.
- Koeppen recognized five major climatic groups, four of them are based on temperature and one on precipitation.
- The capital letters : **A, C, D and E delineate humid climates** and **B dry climates**.
- The climatic groups are subdivided into types, designated by small letters, based on seasonality of precipitation and temperature characteristics.
- The seasons of dryness are indicated by the small letters : f, m, w and s, where **f corresponds to no dry season, m -**

monsoon climate, w - winter dry season and s - summer dry season.

- The small letters a, b, c and d refer to the degree of severity of temperature.
- The B - Dry Climates are subdivided using the capital letters **S for steppe or semi-arid** and **W for deserts**.



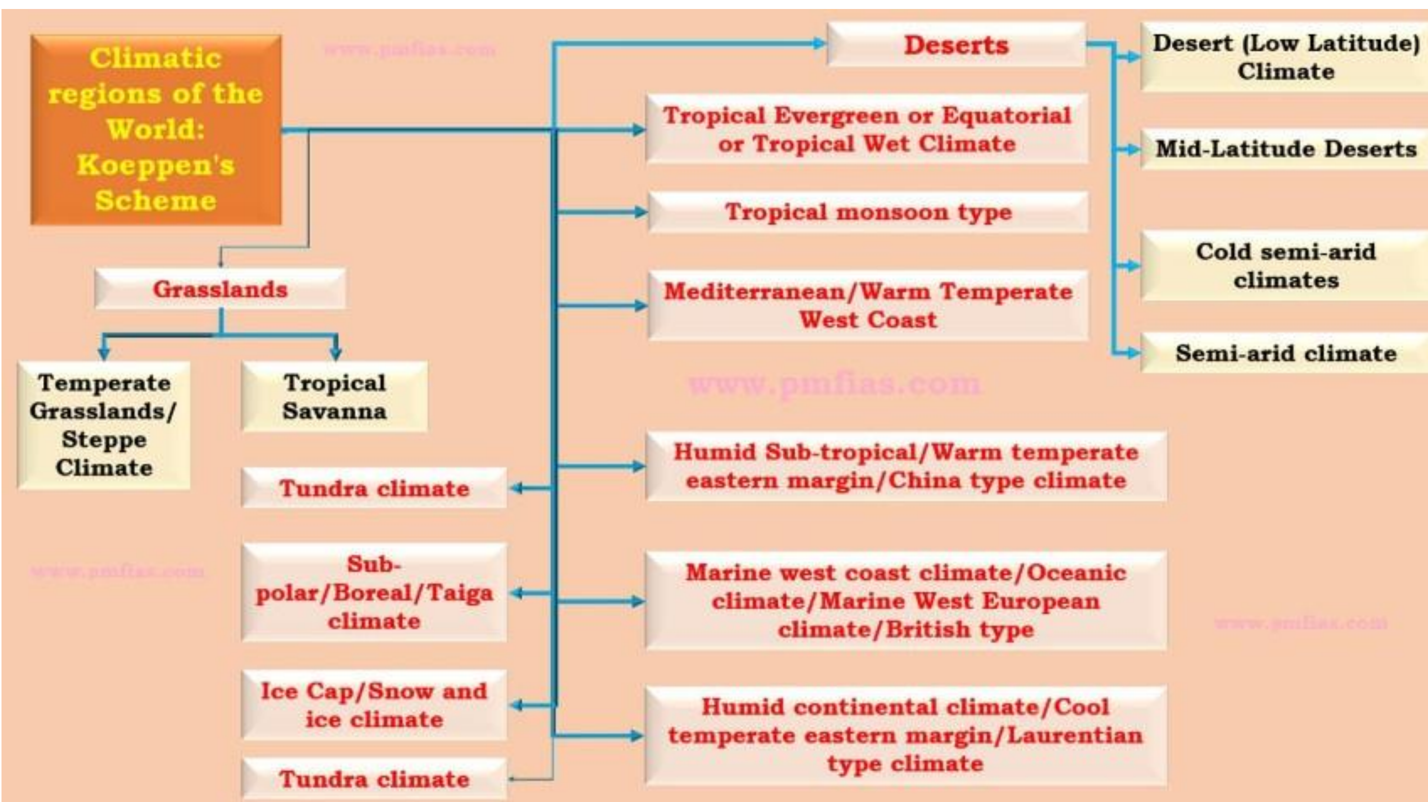


Table 12.1 : Climatic Groups According to Koeppen

Group	*Characteristics*
A - Tropical	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 Climates	The average temperature of the coldest month is minus 3° C or below
E - Cold Climates	Average temperature for all months is below 10° C
H - High Land	Cold due to elevation

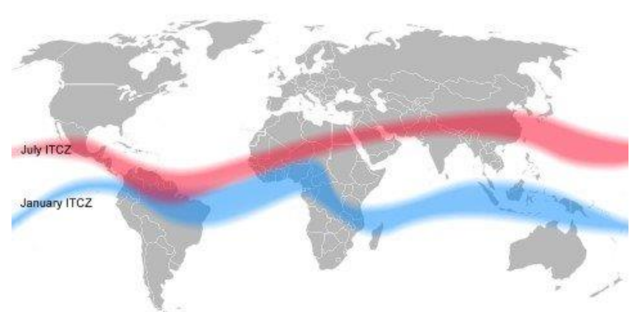
Table 12.2 : Climatic Types According to Koeppen

Group	*Type*	*Letter Code*	*Characteristics*
A-Tropical Humid Climate	Tropical wet	Af	No dry season
	Tropical monsoon	Am	Monsoonal, short dry season
	Tropical wet and dry	Aw	Winter dry season
B-Dry Climate	Subtropical steppe	BSh	Low-latitude semi arid or dry
	Subtropical desert	BWh	Low-latitude arid or dry
	Mid-latitude steppe	BSk	Mid-latitude semi arid or dry
	Mid-latitude desert	BWk	Mid-latitude arid or dry
C-Warm temperate (Mid-latitude) Climates	Humid subtropical	Cfa	No dry season, warm summer
	Mediterranean	Cs	Dry hot summer
	Marine west coast	Cfb	No dry season, warm and cool summer
D-Cold Snow-forest Climates	Humid continental	Df	No dry season, severe winter
	Subarctic	Dw	Winter dry and very severe
E-Cold Climates	Tundra	ET	No true summer
	Polar ice cap	EF	Perennial ice
H-Highland	Highland	H	Highland with snow cover

Group A : Tropical Humid Climates

- Tropical humid climates exist **between** Tropic of Cancer and Tropic of Capricorn.
- The sun being overhead throughout the year and the presence of **Inter Tropical Convergence Zone (INTCZ)** make the climate hot and humid.
- **Annual range of temperature is very low** and **annual rainfall is high**.
- The tropical group is divided into three types, namely

1. **Af – Tropical wet climate;**
2. **Am – Tropical monsoon climate;**
3. **Aw – Tropical wet and dry climate.**

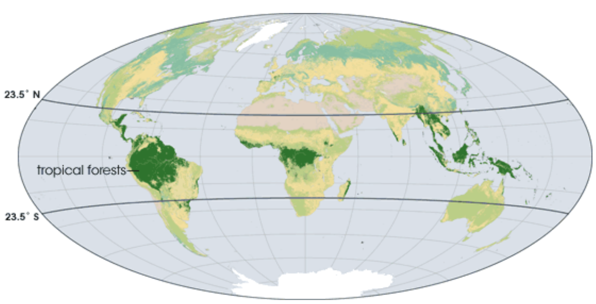


Tropical Wet Climate (Af)

- Also known as '**The Hot, Wet Equatorial Climate**', '**Equatorial Rainforest Climate**'.
- The regions are generally referred as **'Equatorial Rainforests', 'Equatorial Evergreen Forests', 'Tropical Moist Broadleaf Forest', 'Lowland Equatorial Evergreen Rainforest'.**

Distribution

- Mostly between **5° N and S of Equator**. [little or no Coriolis Force == no tropical cyclones]
- Its greatest extent is found in the **lowlands of the Amazon, the Congo, Malaysia and the East Indies.**



Equatorial Climate

- Dominated by **Maritime Tropical air masses**.

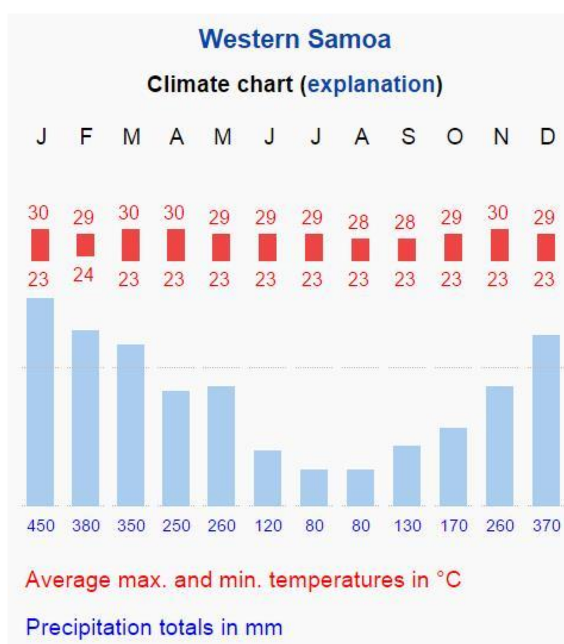
Temperature

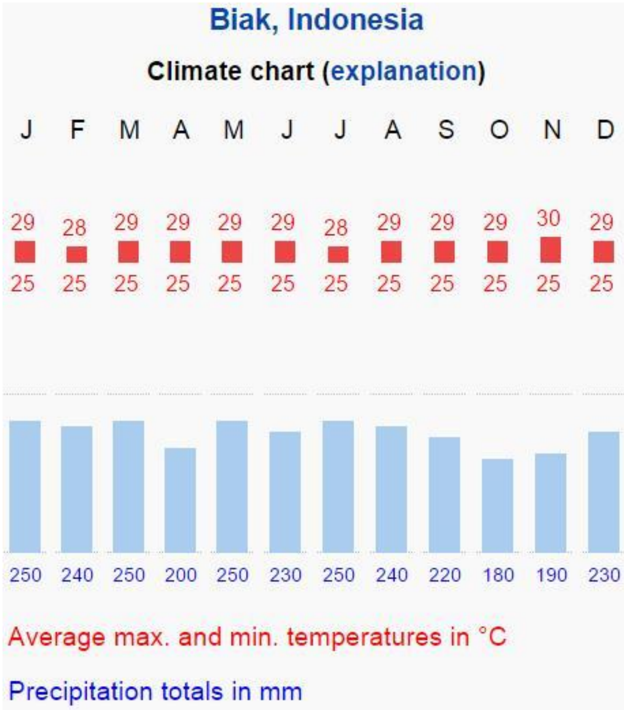
- Temperature is **uniform** throughout the year.
- The mean monthly temperatures are always around **27° C** with very little variation.
- **There is no winter**. [Typical to Equatorial Rainforest Climate]
- Cloudiness and **heavy precipitation** moderate the daily temperature.
- Regular land and sea breezes assist in maintaining a truly equable climate.
- The diurnal range of temperature is **small**, and so is the annual range.

Precipitation

- Precipitation is heavy and **well distributed throughout the year**.
- Annual average is always above **150 cm**. In some regions the annual average may be as high as 250 – 300 cm.
- There is **no month without rain (distinct dry season is absent)**. The monthly average is above **6 cm** most of the times.
- There are two periods of maximum rainfall, **April** and **October**. [shortly after the equinox]. Least rain fall occurs in June and December [**solstice]**.
- The ***double rainfall peaks coinciding with the equinoxes*** are a characteristic feature of equatorial climates not found in any other type of climate.
- There is much evaporation and convectional air currents are set up, followed by **heavy thunderstorms in the afternoons**.

Climate Graphs





Equatorial Vegetation

- High temperature and abundant rainfall support a luxuriant **tropical rain forest**.
- In the Amazon lowlands, the forest is so dense that it is called **'selvas'**. [selvas: A dense tropical rainforest usually having a cloud cover (**dense canopy**)]
- Unlike the temperate regions, the **growing season here is all the year round**-seeding, flowering, fruiting and decaying do not take place in a seasonal pattern.
- The equatorial vegetation comprises a multitude of evergreen trees that yield ***tropical hardwood, e.g. mahogany, ebony, dyewoods etc.***
- Many parts of the tropical rain forests have been cleared either for **lumbering or shifting cultivation.**
- In the coastal areas and brackish swamps, **mangrove forests** thrive.

Canopy

- From the air, the tropical rain forest appears like a thick canopy of foliage, broken only where it is crossed by large rivers or cleared for cultivation.
- All plants struggle upwards (most **ephiphytes**) for sunlight resulting in a peculiar layer arrangement.

Epiphyte: An epiphyte is a plant that grows harmlessly upon another plant (such as a tree) and derives its moisture and nutrients from the air, rain, and sometimes from debris accumulating around it.

- The tallest trees attain a height close to **50 m**.
- The smaller trees beneath form the next layer.
- The ground is rooted with ferns and herbaceous plants which can tolerate shade.
- Because the trees cut out most of the sunlight the **undergrowth is not dense**.

Multiple species

In spite of dense forests, countries in equatorial regions are net importers of timber. Comment.

- Though the tropics have great potential in timber resources, commercial extraction is **difficult.**
- **Multiple species** of trees occur in a particular area (trees do not occur in homogenous stands or pure stands) making commercial exploitation a difficult task.
- Many of the tropical hardwoods (very heavy) **do not float** readily on water and this makes transportation an expensive matter.

- It is therefore not surprising that many tropical countries are **net timber importers**.

Life and Economy

Agriculture

- The forests are sparsely populated.
- In the forests most primitive people live as **hunter gatherers** and the more advanced ones practice **shifting cultivation.**
- Food is abundantly available. People generally don't stock food for the next day.

Commercial

1. In the **Amazon basin** the **Indian tribes** collect wild **rubber**,
2. in the Congo Basin the **Pygmies** gather nuts and
3. in the jungles of Malaysia the **Orang Asli** make all sorts of cane products and sell them to people in villages and towns. *[The names of the tribes come under Social Geography – Prelims]*

Shifting Cultivation or Slash and Burn Cultivation.

- This type of cultivation is followed in many parts of the world where dense forests are common [In India, North-East is known for this type of cultivation].
- Tribes cut the trees in a plot, burn them and cultivate the plot till the fertility is exhausted.
- Once the fertility is exhausted, the clearing is abandoned and they move on to a new plot. Such farming practices are becoming more and more widespread even among backward tribes.
- In the clearings for shifting cultivation, crops like manioc (tapioca), maize, bananas and groundnuts are grown.

Plantation Boom

- With the coming of the Europeans, many large plantations have been established, especially in **Java, Sumatra, Malaysia, West Africa and Central America**.
- The climate is very Favourable for the cultivation of certain crops that are highly valued in the industrial West. The most important is **natural rubber.**
- **Malaysia and Indonesia** are the leading producers. The home country, **Brazil** exports practically no natural rubber.
- **Cocoa** is another important crop which is cultivated in **West Africa**, bordering the **Gulf of Guinea**. The two most important producers are **Ghana and Nigeria**. All the cocoa here goes into American and European **chocolate industry**.
- From the same area another crop, **oil palm**, has done equally well and many countries like Indonesia have now taken to its cultivation.
- Other important crops include coconuts, sugar, coffee (Brazil), tea, tobacco, spices, etc.
- The plantations resulted in the destruction of nearly half of equatorial forests.

Plantations	Regions
Palm	Malaysia, Indonesia
Sugarcane	Brazil
Coffee	Brazil
Rubber	Malaysia, Indonesia
Cocoa	Ghana, Nigeria

Factors Affecting the Development of Equatorial Regions

Equatorial climate and health

- Excessive heat (sun-stroke) and high humidity creates serious physical and mental handicaps.
- High humidity feeds many tropical diseases such as malaria and yellow-fever.
- Communicable diseases are rampant as germs and bacteria are transmitted through moist air.
- Insects and pests not only spread diseases but are injurious to crops.

Jungle hinders development

- The construction of roads and railways is a risky business as workers are exposed to wild animals, poisonous snakes, insects and most importantly tropical diseases.
- Once completed, they have to be maintained at a high cost.

Rapid deterioration of tropical soil

Why does restoration of lost forests take decades in equatorial regions?

- The fertility of top soil in rainforest regions is very poor. Torrential downpours wash out most of the top soil nutrients **[leaching** == percolation and draining way of nutrients due to rain water action**].**
- The soil deteriorates rapidly with subsequent soil erosion and soil impoverishment.
- It takes **decades** to replenish the soil of lost nutrients.
- So a seed doesn't usually germinate and even if it does, its development is hindered due to little availability of sunlight.
- ***Lalang (tall grass)*** and thick undergrowth spring up as soon as the trees are cut. They choke the restoration of forests.
- Indonesian island of Java is an exception because of its rich volcanic ashes.

Difficulties in livestock farming

- Livestock farming is greatly handicapped by an **absence of meadow grass**. The grass is so **tall and coarse** that it is not nutritious.
- The few animals like buffaloes are kept mainly for domestic use. Their yield in milk or beef is well below those of the cattle in the temperate grasslands.
- In Africa, domesticated animals are attacked by **tsetse flies** that cause ngana, a deadly disease.

Mineral resources

- Gold, copper, diamonds, and other precious metals and gemstones are important resources that are found in rainforests around the world.
- Extracting these natural resources is a destructive activity that damages the rainforest ecosystem.
- Examples are **gold mining in the Brazilian and Peruvian Amazon**, **rare earth mining in the Congo**, and **gold and copper mining in Indonesia and Papua New Guinea.**
- Some of the world's most promising oil and gas deposits lie deep in tropical rainforests. **Oil and gas development** often takes a heavy toll on the environment and local people (This happens in Ecuador).
- More than 70 percent of the Peruvian Amazon is now under concession for oil and gas.

Questions

Q1

Assertion (A): Areas near the equator receive rainfall throughout the year.

Reason (R): High temperatures and high humidity cause convectional rain in most afternoons near the equator.

In the context of the above two statements, which one of the following is correct?

a) Both A and R are true and R is the correct explanation of A

b) Both A and R true but R is not a correct explanation of A

c) A is true but R is false

d) A is false but R is true

Q2

Assertion (A) : Areas lying within five to eight degrees latitude on either side of the equator receive rainfall throughout the year.

Reason (R) : High temperatures and high humidity cause convectional rain to fall mostly in the afternoons near the equator. [2003]

a) Both A and R are individually true and R is die correct explanation of A

b) Both A and R are individually true but R is not the correct explanation o f A

c) A is true but R is false

d) A is false but R is true

Q3

A geographic area with an altitude of 400 metres has following characteristics. [2010]

Month	J	F	M	A	M	J	J	A	S	O	N	D
Average maximum temp °C	31	31	31	31	30	30	29	28	29	29	30	31
Average minimum temp °C	21	21	21	21	21	21	20	20	20	20	20	20
Rainfall (mm)	51	85	188	158	139	121	134	168	185	221	198	86

If this geographic area were to have a natural forest, which one of the following would it most likely be?

a) Moist temperate coniferous forest

b) Montane subtropical forest

c) Temperate forest

d) Tropical rain forest

Q4

Assertion (A): Unlike temperate forests, the tropical rain forests, if cleared, can yield productive farmland that can support intensive agriculture for several years even without chemical fertilizers.

Reason (R): The primary productivity of the tropical rain forest is very high when compared to that of temperate forests. [2003]

a) Both A and R are individually true and R is the correct explanation of A.

b) Both A and R are individually true but R is not the correct explanation of A

c) A is true but R is false

d) A is false but R is true

Consider the following statements: [2010]

1. Biodiversity hotspots are located only in tropical regions.
2. India has four biodiversity hotspots i.e., Eastern Himalayas, Western Himalayas, Western Ghats and Andaman and Nicobar Islands.

Which of the statements given above is/are correct?

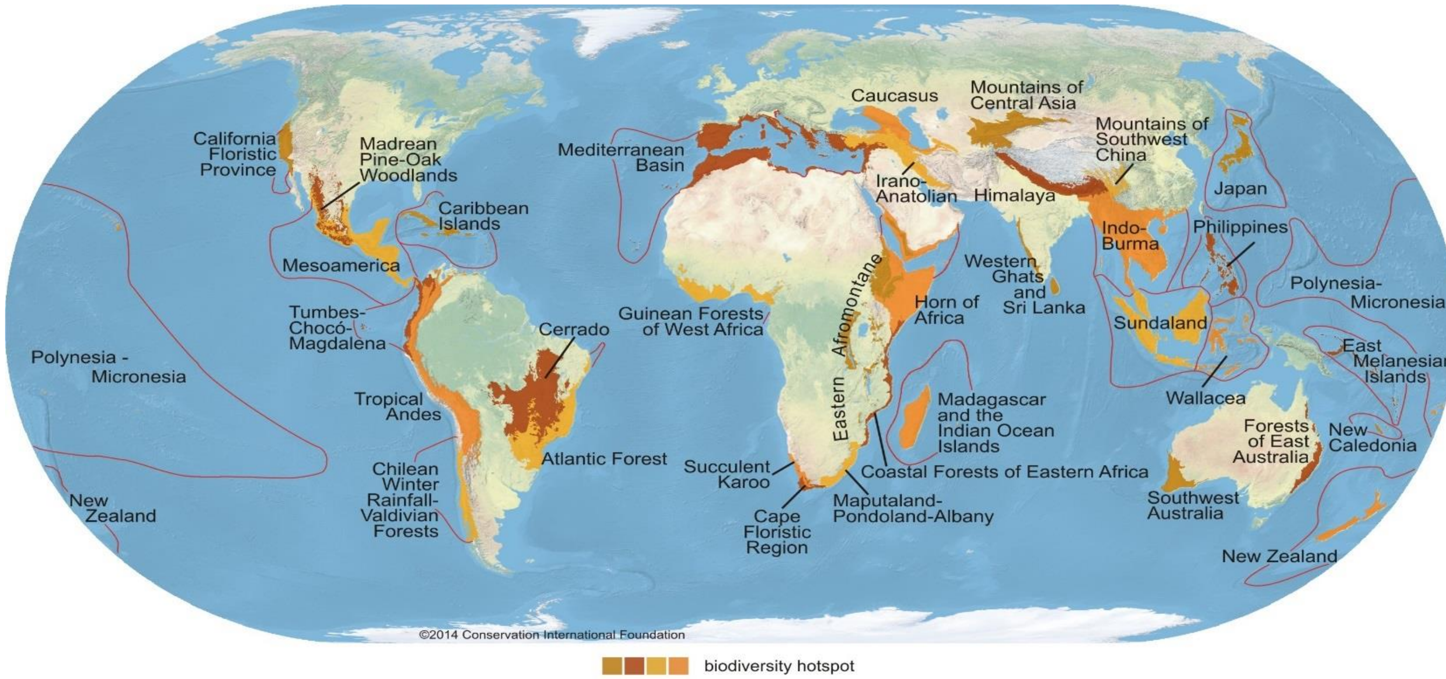
a) 1 only

b) 2 only

c) Both 1 and 2

d) Neither I nor 2

Biodiversity Hotspots Across the World



What type of climate is characterized by two periods of maximum rainfall? Explain why this is so.

- Equatorial Rainforest. Sun is overhead during Equinoxes. So the ITCZ passes twice over the region.

Write brief notes on any three of the following statements about the equatorial regions.

- Large-scale livestock farming is least developed in wet equatorial areas.
- The greatest single drawback to commercial lumbering in equatorial regions is inaccessibility.
- The equatorial environment is best suited to plantation agriculture (Good rainfall, humid climate, cheap labour, good markets in Europe and North America).

In this post : Tropical Monsoon Climate, Tropical Marine Climate and Tropical Monsoon Forests.

Group A : Tropical Humid Climates

- Tropical humid climates exist between Tropic of Cancer and Tropic of Capricorn.
- The sun being overhead throughout the year and the presence of Inter Tropical Convergence Zone (INTCZ) make the climate hot and humid.
- Annual **range of temperature is very low** and **annual rainfall is high**.
- The tropical group is divided into three types, namely

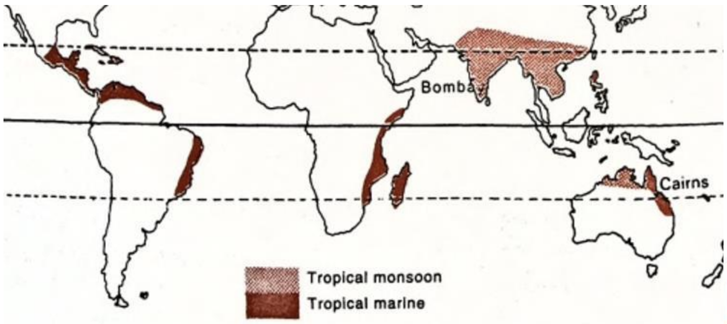
1. **Af- Tropical wet climate [Done in previous post];**
2. **Am - Tropical monsoon climate [This post];**
3. **Aw- Tropical wet and dry climate [Next Post].**

Tropical Monsoon Climate

- Monsoons are **land and sea breezes** on a much larger scale.
- Unlike equatorial wet climate, monsoon climate is characterized by **distinct wet and dry seasons** associated with **seasonal reversal of winds**.
- **Floods** in wet season and **droughts** in dry season are common.
- Usually there are three seasons namely **summer, winter and rainy** season.

Distribution of Tropical Monsoon Climate

- Occur within **5° to 30°** N and S of the equator.
- On-shore [sea to land] tropical monsoons occur in the summer and off-shore [land to sea] dry monsoons in the winter.
- They are best developed in the **Indian sub-continent, Burma, Thailand, Laos, Cambodia, parts of Vietnam and south China and northern Australia**.



Climate

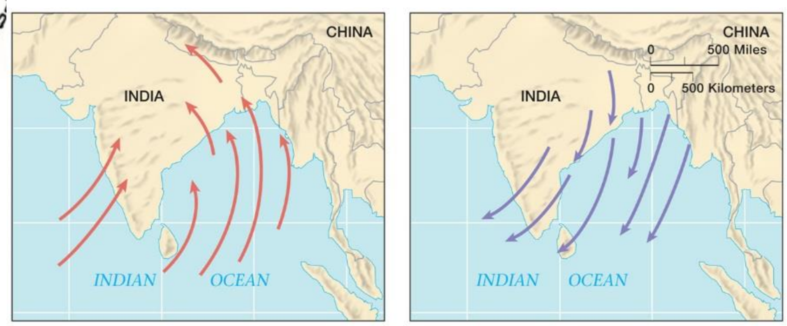
- The basic cause of monsoon climates is the difference in the **rate of heating** and cooling of land and sea (This is old theory. New theory will be explained while studying Indian Climate).
- In the summer, when the sun is overhead at the Tropic of Cancer, a low pressure is created in Central Asia.
- The seas, which warm up much slower, remain comparatively at high pressure. At the same time, the southern hemisphere experiences winter, and a region of high pressure is set up in the continental interior of Australia.
- Winds blow outwards as the South-East Monsoon, to Java, and after crossing the equator are drawn towards the continental low pressure area reaching the Indian sub-continent as the South-West Monsoon (Coriolis force).
- In the winter, conditions are reversed.

Temperature

- Monthly mean temperatures **above 18 °C.**
- Temperatures range from 30-45° C in summer. Mean summer temperature is about 30°C.
- In winters, temperature range is 15-30° C with mean temperature around 20-25° C.

Precipitation

- Annual mean rainfall ranges from 200-250 cm. In some regions it is around 350 cm.
- Places like **Cherrapunji & Mawsynram** receive an annual rainfall of about **1000 cm.** [They lie on the windward side of the Meghalaya hills, so the resulting **orographic lift (orographic rainfall)** enhances precipitation. Also, they are located between mountains which enhances cloud concentration due to **funneling effect**].



Summer Winter

Seasons

- Seasons are chief characteristics of monsoon climate.

The cool, dry season (October to February)

- Out blowing dry winds, the North-East Monsoon, bring little or no rain to the Indian sub-continent.
- However, a small amount of rain falls in Punjab from cyclonic sources (Western Disturbances: Frontal precipitation brought by jet streams) and this is vital for the survival of winter cereals.
- North-East Monsoons blowing over the Bay of Bengal acquires moisture and bring rains to the south-eastern tip of the peninsula at this time of the year (Nov-Dec).

The hot dry season (March to mid-June)

- The temperature rises sharply with the sun's northward shift to the Tropic of Cancer.
- Day temperatures of 35° C are usual in central India and the mean temperature in Sind and south India may be as high as 44° C.
- Coastal districts are a little relieved by sea breezes. There is practically little rain. [Hailstorms (thunderstorms with hail) occurs here and there]

The rainy season (mid-June to September)

- With the 'burst' of the South-West Monsoon in mid-June, torrential downpours sweep across the country. Almost all the rain for the year falls within this rainy season.
- This pattern of **concentrated heavy rainfall** in summer is a characteristic feature of the Tropical Monsoon Climate.

The Retreating Monsoon

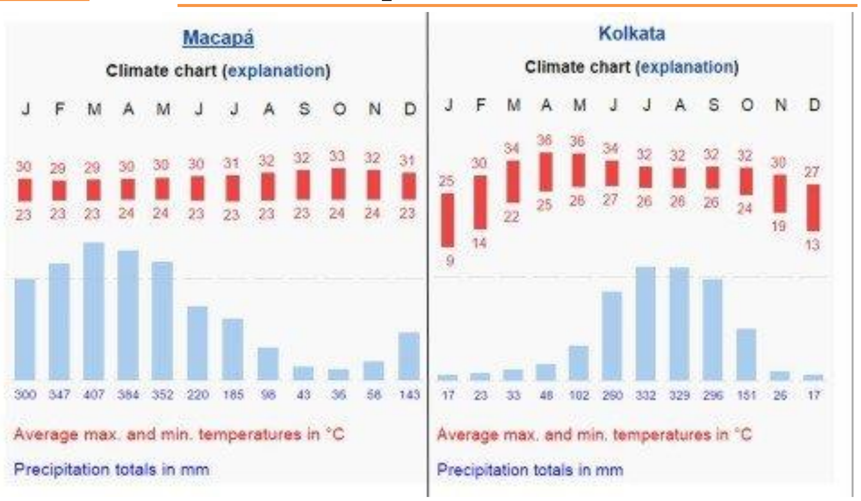
- The amount and frequency of rain decreases towards the end of the rainy season. It retreats gradually southwards after mid-September until it leaves the continent altogether.
- The skies are clear again and the cool, dry season returns in October, with the out blowing North-East Monsoon.

The role of monsoons in India is vital for its economy.

Tropical Marine Climate

- Outside the monsoon zone, the climate is modified by the influence of the on-shore Trade Winds **all the year round**. This type of climate is called Tropical Marine Climate. Such a climate has a more **evenly distributed rainfall**.
- Such a climate is experienced in Central America, West Indies, north-eastern Australia, the Philippines, parts of East Africa, Madagascar, the Guinea Coast and eastern Brazil.
- The rainfall is both **orographic** where the moist trades meet upland masses as in eastern Brazil, and **convectional** due to intense heating during the day and in summer.
- Its tendency is towards a summer maximum without any distinct dry period.
- Due to the steady influence of the trades, the Tropical Marine Climate is **more Favourable for habitation**, but it is **prone to severe tropical cyclones, hurricanes or typhoons.**

Climate Graph



Tropical Monsoon Forests

Drought-deciduous forest; dry forest; dry-deciduous forest; tropical deciduous forest.

- **Broad-leaved hardwood trees**. Well developed in **southeast Asia.**
- Trees are normally deciduous, because of the marked dry period, during which they shed their leaves to withstand the drought [They shed their leaves to prevent loss water through **transpiration**].
- The forests are more open and **less luxuriant** than the equatorial jungle and there are far **fewer species.**
- Where the rainfall is heavy, e.g. in southern Burma, peninsular India, northern Australia and coastal regions with a tropical marine climate, the resultant vegetation is luxuriant.

- With a decrease in rainfall in summer, the forests thin out into **thorny scrubland or savanna** with scattered trees and tall grass.
- In parts of the Indian sub-continent, rainfall is so deficient that semi-desert conditions are found in summer. Monsoonal vegetation is thus most varied, ranging from forests to thickets, and from savanna to scrubland.

Population and Economy in Monsoon Climate

- Monsoon climatic regions support high population density.
- Income levels are low as most of these regions are underdeveloped or developing.
- Subsistence farming is the main occupation. (crops grown with an intention to secure food for the season. The crops are not sold as the production is very low).
- Intensive cultivation is common in regions with irrigational facilities.
- Shifting cultivation is followed in North-East India and South-East countries.
- Major crops include rice, sugar, cotton, jute, spices, etc..
- Cattle and sheep rearing is carried out for domestic and commercial purposes. Livestock industry is not as profitable as in temperate regions.

Agricultural Development in the Monsoon Lands

- Much of the monsoon forest has been cleared for agriculture to support the very dense population. Subsistence agriculture is the major occupation.
- Farms are small and the people are forever **'land hungry.'** Industrialization make things worse.
- Tropical agriculture dependent on natural rainfall and a large labour force, reaches its greatest magnitude in the monsoon lands.
- Farming is the dominant occupation of the Indian sub-continent, China, South- East Asia, eastern Brazil and the West Indies. The following types of agriculture are recognizable.

Crops

- Rice is the most important staple crop.
- Irrigation water from rivers, canals, dams or wells is extensively used in the major rice producing countries.
- Other food crops like maize, millet, sorghum, wheat, gram and beans are of subsidiary importance. They are cultivated in the drier or cooler areas where rice cannot be grown.

Lowland cash crops

- The most important crop in this category is **cane sugar**.
- As much as two-thirds of world's sugar production comes from tropical countries.
- Some of the major producers include **India, Java, Formosa, Cuba, Jamaica, Trinidad and Barbados.**
- **Jute** is confined almost entirely to the Ganges - Brahmaputra delta, in India and Bangladesh.
- Other crops include cotton, a major commercial crop of the Indian sub-continent.

Highland plantation crops

- The colonization of tropical lands by Europeans gave rise to a new form of cultivated landscape in the cooler monsoonal highlands.
- Thousands of acres of tropical upland forests were cleared to make way for plantation agriculture in which tea and coffee are the most important crops.

Coffee

- Coffee originated in Ethiopia and Arabia.
- But **Brazil** accounts for almost half the world's production of coffee.
- It is mainly grown on the eastern slopes of the Brazilian plateau.
- The crop is also cultivated on the highland slopes in the Central American states, India and eastern Java.

Tea

- Tea originated in China and is still an important crop there.
- It requires **moderate temperatures** (about 15° C), **heavy rainfall** (over 150 cm) and **well drained highland slopes.**
- It thrives well in the tropical monsoon zone (highlands).
- The best regions are thus the Himalayan foothills of India and Bangladesh, the central highlands of Sri Lanka and western Java, from all of which it is exported.
- In China tea is grown mostly for local consumption.

Lumbering

- Most of the forests yield valuable timber, and are prized for their **durable hardwood.**
- Lumbering is undertaken in the more accessible areas. This is particularly important in continental South-East Asia.
- Of the tropical deciduous trees, **teak,** of which **Burma** is the leading producer, is perhaps the most sought after. It is valuable on account of its **great durability, strength, immunity to shrinkage, fungus attack and insects.**
- Teak logs are so heavy that they will not float readily on water. It is therefore necessary to 'poison' the tree several years before actual felling, so that it is dry and light enough to be floated down the **Chindwin** and the **Irrawaddy** to reach the saw mills at **Rangoon.**
- Other kinds of timber include **Neem, Banyan, Mango, Teak, Sal, Acacia, Eucalyptus**
- Together with the forests are bamboo thickets, which often grow to great heights.

Teak

- Burma alone accounts for as much as three – quarters of the world's production.
- It is such a durable timber that it is extensively used for **ship building**, furniture and other constructional purposes.

Shifting Cultivation

- This most primitive form of farming is widely practiced.
- Instead of rotating the crops in the same field to preserve fertility, the tribesmen move to a new clearing when their first field is exhausted.
- Maize, dry padi, sweet potatoes and some beans are the most common crops.
- Farming is entirely for **subsistence**, i.e. everything is consumed by the farmer's family, it is not traded or sold.
- As tropical soils are **rapidly leached and easily exhausted, the first crop may be bountiful but the subsequent harvests deteriorate.**
- Shifting cultivation is so widely practiced amongst indigenous peoples that different local names are used in different countries.

Region	Name of Shifting Cultivation
Malaysia	Lacking
Burma	Taungya
Thailand	Tamrai
Philippines	Caingin
Java	Humah
Sri Lanka	Chena
Africa and Central America	Milpa
North-east India	**Jhum**

Can be a [tough] prelims question under social geography.

Questions

Explain the following statements.

(a) The east coasts of continents within the tropics have much heavier rainfall than the interiors or the west coasts [Hint: Easterly trade winds].

(b) Near the equatorial latitudes, the period of maximum rainfall is closely related to the movements of the overhead sun [Hint: Inter-Tropical Convergence Zone shifts according to the apparent movement of the Sun].

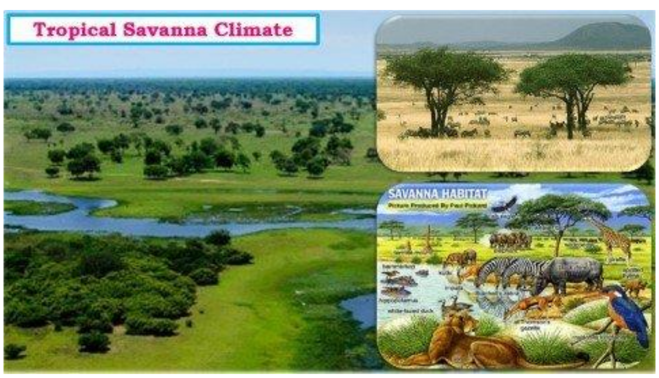
(c) There is a marked difference in temperature between the east and west coasts of countries in latitudes 20° to 35°N [Hint: Ocean currents].

The seasonal reversal of winds is the typical characteristic of

1. Equatorial climate
2. Mediterranean climate
3. Monsoon climate
4. All of the above climates

In this post: Savanna Climate or Tropical Wet and Dry Climate or Sudan Climate, Distribution of Savanna Climate, Savanna Climate, Natural Vegetation of Savanna Climate and Life and Economy in the Savanna.

Savanna Climate or Tropical Wet and Dry Climate or Sudan Climate



- This type of climate has **alternate wet and dry seasons** similar to monsoon climate but has **considerably less annual rainfall**.
- Also, there is **no distinct rainy season** like in monsoon climate.

[Only two seasons – winter and summer. **Rains occur in summer**].

- Floods and droughts are common.
- Vegetation, wildlife and human life are quite different from monsoon climate regions.

Distribution of Savanna Climate

- It is confined within the tropics and is best developed in **Sudan**, hence its name the **Sudan Climate**.
- It is a **transitional type** of climate found between the **equatorial rainforests** and **hot deserts.**

African Savanna

- The belt includes **West African Sudan**, and then curves southwards into East Africa and southern Africa north of the Tropic of Capricorn.

South American Savanna

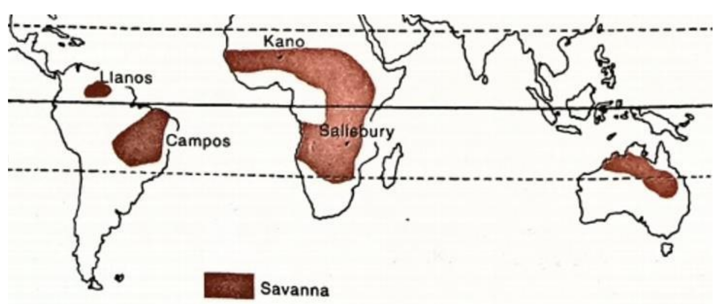
- There are two distinct regions namely the **llanos** of the Orinoco basin [north of equator] and the **compos** of the Brazilian Highlands [South of equator].

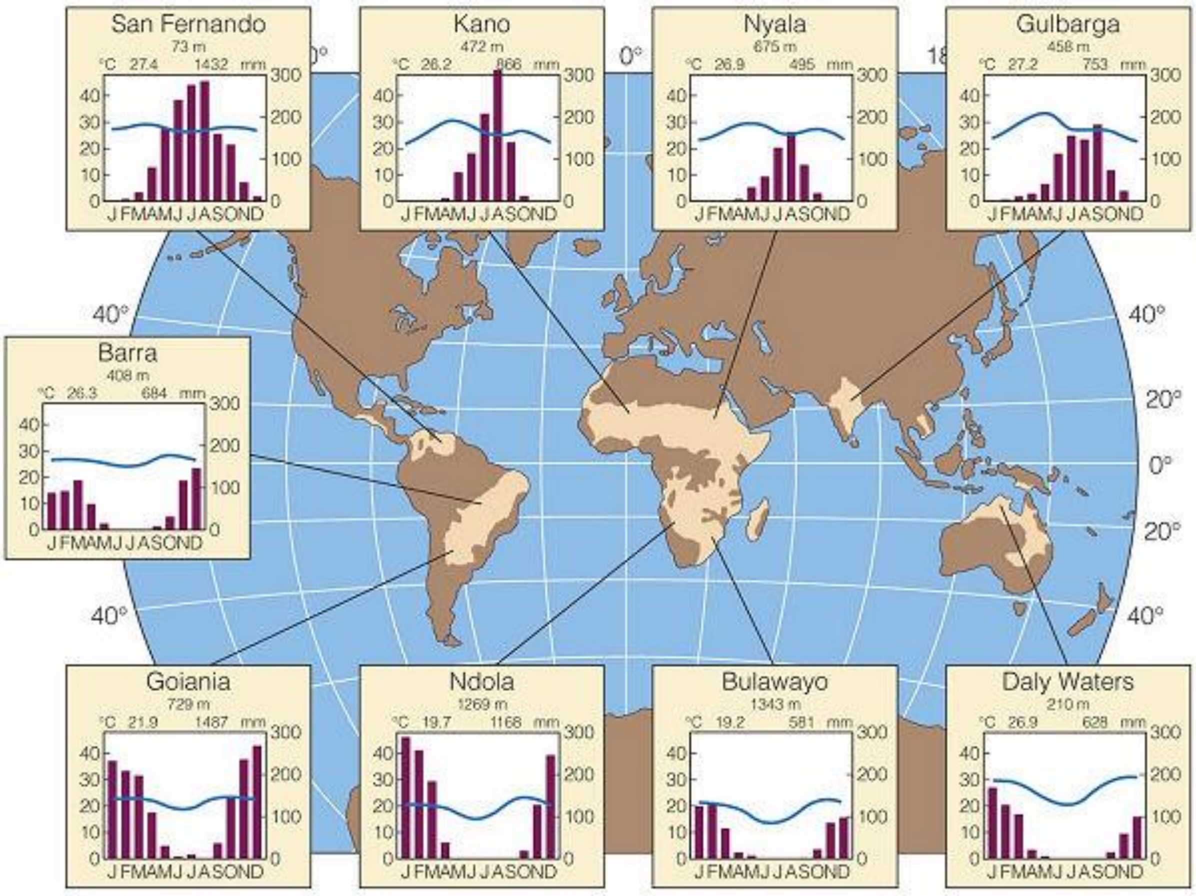
Australian savanna

- The Australian savanna is located south of the monsoon strip (northern Australia) running from west to east north of the Tropic of Capricorn.

Indian Savanna

- Certain parts across Northern Karnataka, Southern Maharashtra and Telangana exhibit characteristics of both semi-arid and savanna climate.
- Due to irrigation and cultivation, this region is different from other savanna regions.





Savanna Climate

Rainfall

- Mean annual rainfall ranges from **80 – 160 cm** [Rainfall decreases with distance from equator].
- In the northern hemisphere, the rainy season begins in May and lasts till September.
- In the southern hemisphere, the rainy season is from October to March.

Temperature

- Mean annual temperature is **greater than 18° C.**
- The monthly temperature hovers between 20° C and 32° C for lowland stations.
- **Highest temperatures do not coincide with the period of the highest sun** (e.g. June in the northern hemisphere) but occur just before the onset of the rainy season, i.e. April in Northern Hemisphere and October in Southern Hemisphere.
- **Days are hot and nights are cold**. This **extreme diurnal range** of temperature is another characteristic feature of the Sudan type of climate.

Winds

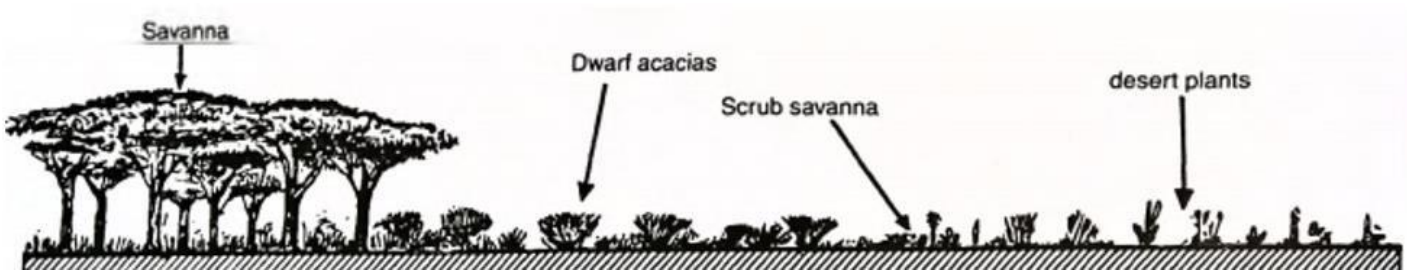
- The prevailing winds of the region are the Trade Winds, which bring rain to the coastal districts.
- They are strongest in the summer [favorable position of ITCZ] but are relatively dry by the time they reach the continental interiors or the western coasts [Trade winds are easterlies – flow from east to west. So rainfall decreases from east to west here].
- In West Africa, the North-East Trades, in fact, blow off-shore [continent to sea] from the Sahara Desert and reach the Guinea coast as a dry, dust-laden winds.

What is the reason for alternating wet and dry seasons in Savanna type climate?

- On shore winds is summer bring rains.
- Off-shore winds in winter keep the climate dry.

Natural Vegetation of Savanna Climate

- The savanna landscape is typified by **tall grass and short trees**.
- The grasslands are also called as ***'bush-veld'.***
- The trees are **deciduous**, shedding their leaves in the cool, dry season to prevent excessive loss of water through transpiration, e.g. acacias.
- Trees usually have **broad trunks**, with water-storing devices to survive through the prolonged drought.
- Many trees are umbrella shaped, exposing only a narrow edge to the strong winds.
- In true savanna lands, the grass is **tall and coarse**, growing 6 to 12 feet high. The **elephant grass** may attain a height of even 15 feet.
- Grasses appear greenish and well-nourished in the rainy season but turns yellow and dies down in the dry season that follows.
- As the rainfall diminishes towards the deserts the savanna merges into thorny scrub.



Animal Life of the Savanna

- The savanna is known as the **'big game country'** as thousands of animals are trapped or killed each year by people from all over the world.
- There are two main groups of animals in the savanna, the grass-eating herbivorous animals and the fleshing-eating carnivorous animals.
- The herbivorous include the zebra, antelope, giraffe, deer, gazelle, elephant etc. [most of the National geographic and Animal Planet documentaries on wild animals are shot in savanna regions] and carnivorous animals include the lion, tiger, leopard, hyena, panther, jaguar, jackal etc..
- Species of reptiles and mammals including crocodiles, alligators, giant lizards live together with the larger rhinoceros and hippopotamus in rivers and marshy lakes.

Life and Economy in the Savanna

- Many tribes live in savanna region. Tribes like the **Masai** tribes of the East African plateau are pastoralists whereas **Hausa** of northern Nigeria are settled cultivators.
- The old grazing grounds of Masai tribes in the **Kenyan Highlands** were taken over by the immigrant white settlers for plantation agriculture (coffee, tea, cotton) and dairy farming.
- The cattle kept by the Masai are kept entirely for the supply of milk. They don't slaughter cattle for meat. **Agriculture is barely practiced**.
- The Hausa are a tribe of settled cultivators who inhabit the savanna lands of the Nigeria. They are more advanced in their civilization.
- They do not practice shifting cultivation. Instead, they clear a piece of land and use it for several years.

Crops in Savanna

- Settlements in central Africa, northern Australia and eastern Brazil have shown that the savannas have immense agricultural potential for **plantation agriculture** of cotton, cane sugar, coffee, oil palm, groundnuts and even tropical fruits.

- Tropical Queensland, despite its scarcity of labour force has been very successful in developing its huge empty land.
- Kenya, Uganda, Tanzania and Malawi have already taken to large-scale production of cotton.
- In West Africa, the commercial cultivation of groundnuts, oil palm and cocoa have been gradually extended into the savanna lands.
- In the cooler highlands, temperate crops have been successfully raised.

Farming

- Droughts are long due to unreliable rainfall.
- Political instability hinders the development of agricultural infrastructure.
- The Sudan Climate, with **distinct wet-and-dry periods** is also responsible for the **rapid deterioration of soil fertility**.
- During the rainy season, torrential downpours of heavy rain cause leaching of nitrates, phosphates and potash.
- During the dry season, intense heating and evaporation dry up most of the water.
- Many savanna areas therefore have **poor lateritic soils** which are incapable of supporting good crops.

Cattle rearing

- The savanna is said to be the **natural cattle country** and many of the native people are pastoralists.
- But the **quality of grass doesn't support large scale ranching**.
- Grasses here are no match to nutritious and soft grasses of temperate grasslands.
- The cattle varieties are also poor and yield little meat or milk.
- The export of either beef or milk from the tropical grasslands is so far not important.
- Few regions progressed with the adaptation of science and technology. **Queensland** has become Australia's largest cattle producing state. Both meat and milk are exported.

QUESTIONS

Explain why

- The savanna is the **natural home of cattle**.
- Rainfall in the Sudan Climate is concentrated in the summer.

Which one of the following is the characteristic climate of the Tropical Savannah Region? [2012]

1) **Rainfall throughout the year**
2) **Rainfall in winter only**
3) **An extremely short dry season**
4) **A definite dry and wet season**

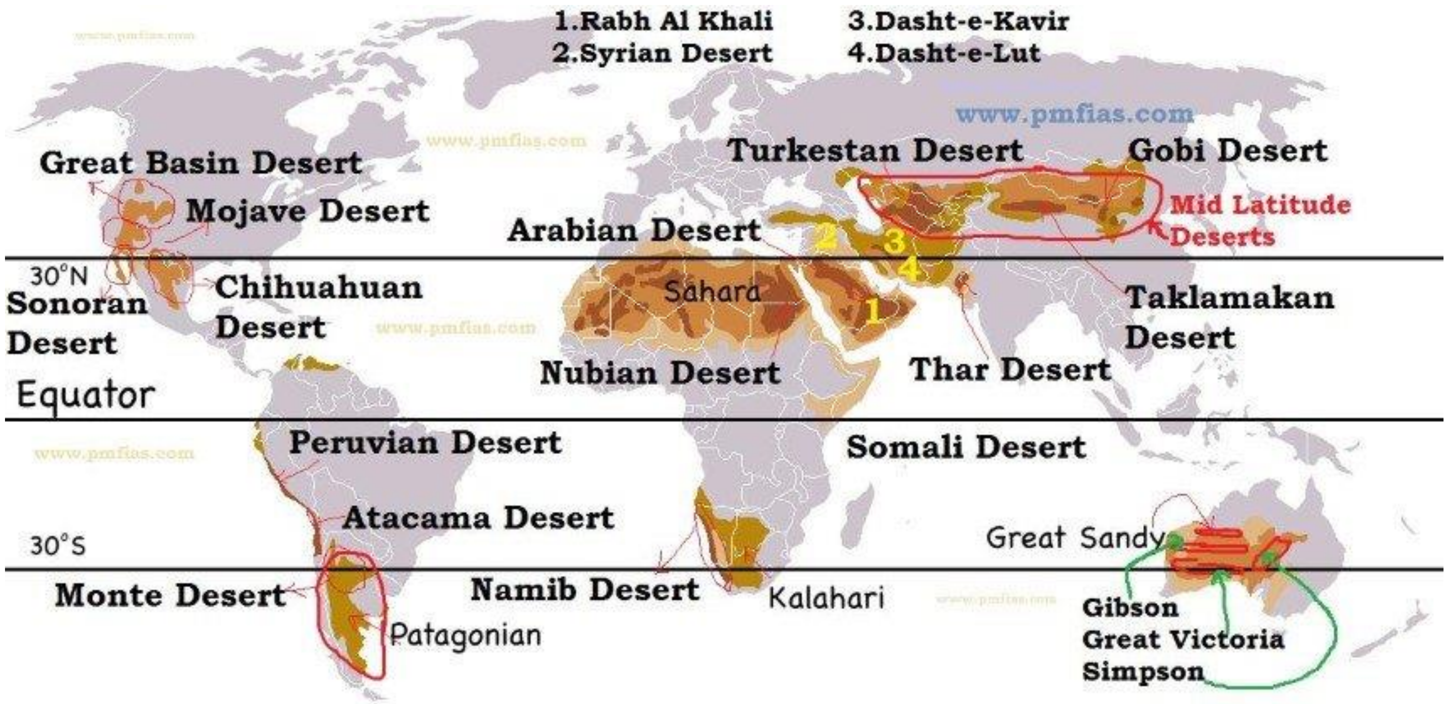
In this post: Desert Climate, Hot Desert Climate, Mid-Latitude Desert Climate and Life in the Deserts.

B: Desert Climate

- 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**, hence they are also called **Trade Wind Deserts.**
- The major hot deserts of the world are located on the **western coasts of continents** between latitudes 15° and 30°N. and S (Question asked in Previous Mains Exam).
- 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 **continentiality or rain-shadow effect.** [**Gobi desert** is formed due to **continentiality** and **Patagonian desert** due to **rain-shadow effect**]
- Amongst the mid-latitude deserts, many are found on plateau and are at a considerable distance from the sea. These are **Ladakh, The Kyzyl Kum, Turkestan, Taklimakan and Gobi deserts of Central Asia, drier portions of the Great Basin Desert of the western United States** and **Patagonian Deserts of Argentina etc..**
- The Patagonian Desert is more due to its rain-shadow position on the leeward side of the lofty Andes than to continentiality.

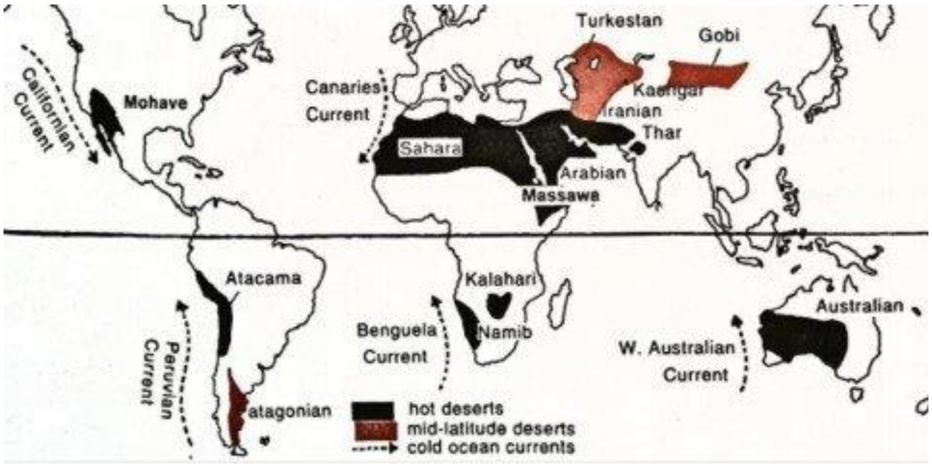
Desert Climate

Rainfall (Both Hot and Cold deserts)

- Deserts, whether hot or mid-latitude have an annual precipitation of **less than 25 cm.**
- **Atacama (driest place on earth)** has practically no rain at all.
- Rain normally occurs as violent thunderstorms of the convectional type.
- It 'bursts' suddenly and pours continuously for a few hours over small areas.

- The thunderstorm is so violent, and comes so suddenly that it has disastrous consequences on desert landforms [flash floods].

Major hot deserts in northern hemisphere are located between 20-30 degree north and on the western side of the continents. Why?



- The hot deserts lie along the **Horse Latitudes or the Sub-Tropical High Pressure Belts** where the air is descending, a condition least favorable for precipitation of any kind to take place.
- The rain-bearing Trade Winds blow **off-shore** and the Westerlies that are on-shore blow outside the desert limits.
- Whatever winds reach the deserts **blow from cooler to warmer regions**, and their **relative humidity is lowered**, making condensation almost impossible.
- There is scarcely any cloud in the continuous blue sky. The relative humidity is extremely low, decreasing from 60 per cent in coastal districts to less than 30 per cent in the desert interiors. Under such conditions, every bit of moisture is evaporated and the deserts are thus regions of permanent drought. Precipitation is both scarce and most unreliable.
- On the western coasts, the presence of cold currents gives rise to **mists and fogs** by chilling the on-coming air. This air is later warmed by contact with the hot land, and little rain falls. The desiccating effect of the **cold Peruvian Current** along the Chilean coast is so pronounced that the mean annual rainfall for the Atacama Desert is not more than 1.3 cm.

Temperature of Hot deserts

- There is no cold season in the hot deserts and the average summer temperature is high around 30°C.
- The highest temperature recorded is **57.77° C in 1922 at A1 Azizia, Libya.** The reasons for the high temperatures are obvious—a clear, cloudless sky, intense insolation, dry air and a rapid rate of evaporation. Coastal deserts by virtue of their maritime influence and the cooling effect of the cold currents have much lower temperatures.
- The desert interiors, however, experience much higher summer temperatures and the winter months are rather cold.
- The diurnal range of temperature in the deserts is very great. Intense insolation by day in a region of dry air and no clouds causes the temperature to rise with the sun.
- But as soon as the sun sets, the land loses heat very quickly by radiation and the mercury levels drop.
- **High diurnal temperature range** is a typical feature of hot deserts. Average diurnal range varies from 14 to 25° Celsius.
- Frosts may occur at night in winter.

Climatic Conditions in the Mid-Latitude deserts

- These inland basins lie hundreds of miles from the sea, and are sheltered by the high mountains all around them. As a result they are **cut off from the rain-bearing winds**.
- Occasionally depressions may penetrate the Asiatic continental mass and bring light rainfall in winter. Due to their

coldness and elevation, snow falls in winter.

- The annual range of temperature is **much greater** than that of the hot deserts. **Continentiality** accounts for these extremes in temperature.
- Winters are often severe, freezing lakes and rivers, and strong cold winds blow all the time. When the ice thaws in early summer, floods occur in many places.

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.**
- Along the western coastal deserts washed by cold currents as in the Atacama Desert, support a thin cover of vegetation.
- Intense evaporation increases the salinity of the soil so that the dissolved salts tend to accumulate on the surface forming hard pans [Bajada, Palaya].
- 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. Plants have few or no leaves and the foliage is either **waxy, leathery, hairy or needle-shaped** to reduce the loss of water through transpiration.
- 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 same way, desert cultivators rely on the **Indus in Pakistan**, the **Tigris-Euphrates in Iraq**, and the **Colorado in the Imperial Valley of California**.
- 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.
- Some of them are abnormally large like the **Tafilalet Oasis in Morocco** which measures 5,000 square miles.
- A wall is usually constructed around the oasis to keep out the violent dust storms called **simooms.**
- 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.

The mining settlers

- It was **gold** that brought immigrants scrambling into the Great Australian Desert.
- Some of them like **Kalgoorlie and Coolgardie** have become towns of considerable size.
- In the Kalahari Desert, the discovery of **diamonds** and **copper** has brought many white men to the 'thirstland' as it is called.
- Even in the most arid Atacama, in northern Chile, large mining camps have been established for the mining of **caliche (cemented gravels)** from which **sodium nitrate**, a valuable fertilizer, is extracted and exported to all parts of the world.
- Besides nitrates, **copper** is also mined. **Chuquicamata** is the world's largest copper town.
- Similarly in the deserts of North America, silver is mined in Mexico, uranium in Utah and copper in Nevada.
- In recent years, the discovery of oil, in many parts of the Saharan and Arabian Deserts has transformed this forgotten part of the globe.
- Saudi Arabia, Iran, Iraq, Kuwait, Algeria, Libya, Lebanon, Nigeria etc. are important oil producing desert countries.

QUESTIONS

Explain how the aridity of the desert is related to

- off-shore Trade Winds
- the Sub-Tropical High Pressure Belts (the Horse Latitudes)
- cold ocean currents

Bring out any distinct differences between the hot deserts and mid-latitude deserts in

- climate
- vegetation
- way of life

Explain any three of the following.

- The hot deserts of the world are located on the western coasts of continents.
- Patagonia is a desert in the rain shadow of the Andes.
- The annual range of temperature is much greater at Kashgar (Gobi) than at Iquique (Atacama).

Write brief notes on any three of these topics.

- Date palm cultivation in an oasis.
- The role of oil in the development of desert economy.

In this post: Steppe Climate or Temperate Continental Climate or Temperate Grassland Climate, Natural Vegetation of Steppe Climate, Economic Development of Steppes and Maps: Savanna Grasslands and Steppe Grasslands.

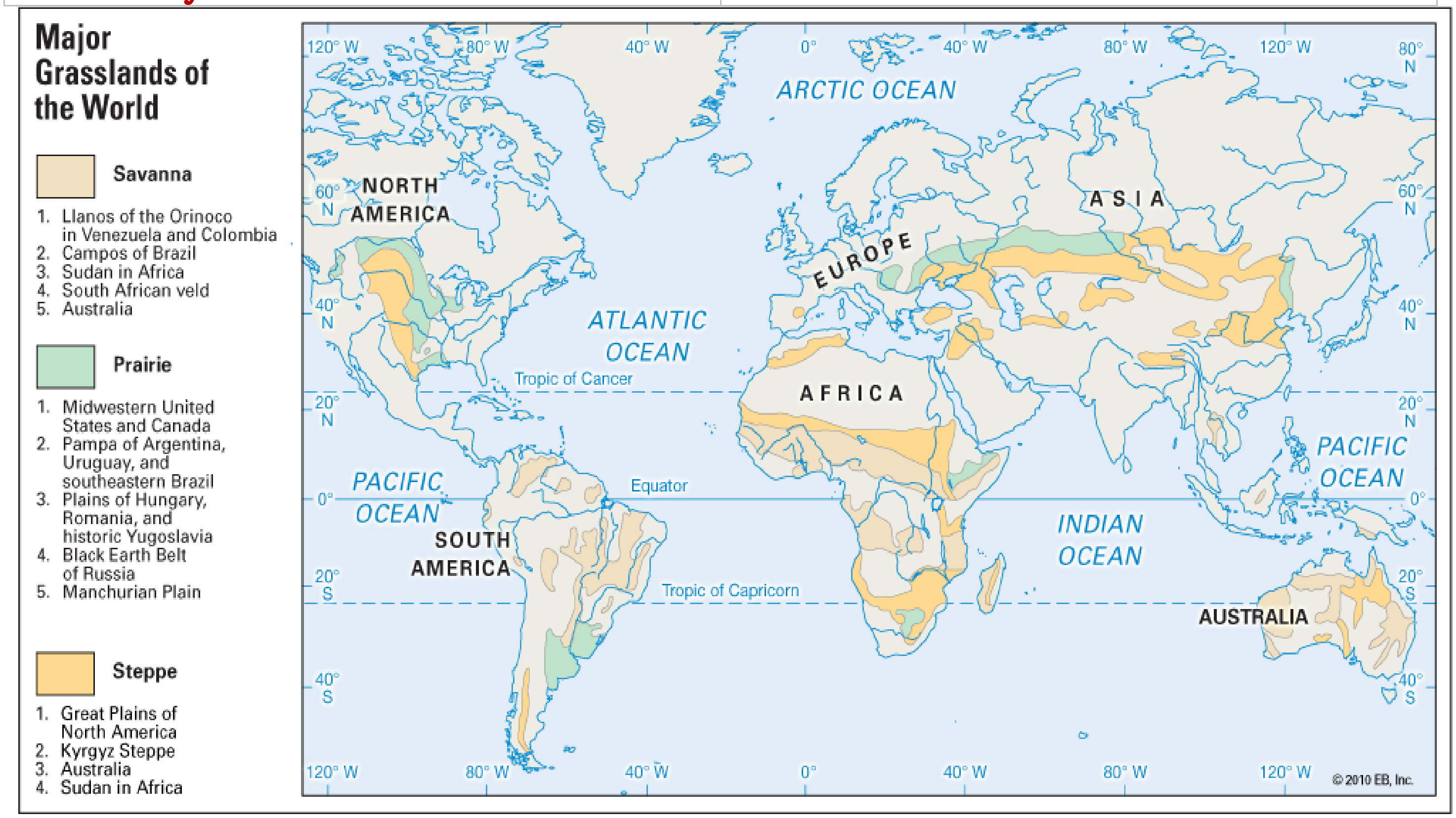
Steppe Climate or Temperate Continental Climate or Temperate Grassland Climate

Distribution

- They lie in the **interiors of the continents**.
- Lie in the **Westerly wind belt [mid-latitudes or temperate region]**.
- Grasslands are practically treeless due to continentiality [deep within the interiors of the continents where rain bearing winds don't reach].
- In Eurasia, they are called the **Steppes**, and stretch eastwards from the shores of

the Black Sea to the foothills of the Altai Mountains. [2,000 miles long belt].

Name of the Temperate Grassland	**Region**
Pustaz	Hungary and surrounding regions
Prairies	North America [between the foothills of the Rockies and the Great Lakes]
Pampas	Argentina and Uruguay [Rain-shadow effect]
Bush-veld (more tropical)	Northern South Africa
High Veld (more temperate)	Southern South Africa
Downs	Australia: Murray-Darling basin of southern Australia
Canterbury	New Zealand



Steppe Climate

Temperature

- Climate is continental with **extremes of temperature**.
- Temperatures vary greatly between summer and winter.
- The summers are hot and the winters are cold.
- Summers are very warm, over 18 – 20° C.
- The steppe type of climate in the southern hemisphere is never severe.

Precipitation

- The average rainfall may be taken as about 45 cm, but this varies according to location from 25 cm to 75 cm.
- The heaviest rain comes in June and July (late spring and early summer).
- Most of the winter months have about an 2.5 cm of precipitation, brought by the occasional depressions of the Westerlies and coming in the form of snow.
- The maritime influence in the southern hemisphere causes more rainfall.

Chinook: Local winds in Steppe regions

- On the eastern slopes of the Rockies in Canada and U.S.A. a local wind, similar to the Fohn in Switzerland, called the

Chinook, comes in a south-westerly direction to the Prairies and has a considerable effect on the local pastures.

- It actually comes with the depressions in winter or early spring from the Pacific coast ascending the Rockies and then descending to the Prairies [katabatic wind].
- It is a hot wind and may raise the temperature by 5° C within a matter of 20 minutes.
- It melts the snow-covered pastures and animals can be driven out of doors to graze in the open fields. The agricultural year is thus accelerated.
- Local farmers welcome the Chinook for frequent. Chinooks [**Snow eaters**] mean mild winters.

[Other important Local Winds in different regions: Loo, Mistral, Sirocco, Foehn etc.]

Natural Vegetation of Steppe Climate

Grasses

- Greatest difference from the tropical savanna is that steppes are practically **treeless** and the **grasses are much shorter**.
- Grasses are tall, fresh and **nutritious**. This is typical of the grass of the wheat-lands in North America, the **rich black earth or chernozem areas of Russian Ukraine** and the better watered areas of the Asiatic Steppes.
- Where the rainfall is light or unreliable, or the soil is poor, as in the continental interiors of Asia the short steppe type of grass prevails.
- The grasses are not only shorter but also **wiry [**lean, tough**] and sparse [**thinly dispersed or scattered**]**.
- These areas are **less suitable for arable farming** and are used for some form of **ranching** as in the High Plains of U.S.A.
- The growth of grasses is not abruptly checked by summer droughts or winter cold.

Trees

- Polewards, an increase in precipitation gives rise to a transitional zone of wooded steppes where some **conifers** gradually appear.
- In the cultivated regions, such as the wheat farms of the Prairies, double rows of trees are planted around the house to shield the occupants from the strong wind.

Animals

- Does not have much animal diversity.
- **Horses** are common in Asian Steppes.

Economic Development of Steppes

Wheat and Maize Cultivation

- Cultivation was unknown just before a century and the region was one of the most sparsely populated parts of the world.
- In recent years, the grasslands have been ploughed up for extensive, mechanized wheat cultivation and are now the **'granaries of the world' [Prairies].**
- Besides wheat, maize is increasingly cultivated in the warmer and wetter areas.

Ranching

- The tufted grasses have been replaced by the more **nutritious Lucerne or alfalfa grass** for cattle and sheep rearing.
- These temperate grasslands are now the **leading ranching regions** of the globe.

Nomadic herding in Asian Steppes

- This type of migratory animal grazing has almost disappeared from the major grasslands. The herders were wandering tribes e.g. the **Kirghiz**, and the **Kazakhs.**
- The harsh environment of the nomads, with long droughts and unreliable showers made the Kirghiz a tough and fearless people, and they long resisted subjugation by the Russians.
- Now, however, under the Communist regime they are being forced to settle down.

- The steppes have been made into huge **collective farms** and state farms for ranching or producing cereals.

Extensive mechanized wheat cultivation

- The **temperate grasslands** are ideal for extensive wheat cultivation.
- The **level ness** of the Steppes and other temperate grasslands all over the world makes ploughing and harvesting a comparatively easy job.
- In the **Prairies, the Argentinian Pampas, the Ukrainian Steppes** and the **Downs of Australia**, agriculture is completely mechanized.

Pastoral farming

- The natural conditions suit animal farming.
- With the development of refrigerated ships in the late nineteenth century, the temperate grasslands became major pastoral regions, exporting large quantities of beef, mutton, wool, hides.
- Milk, butter, cheese and other dairy products are also important in some parts of the North American grasslands.

Grassland	Major Economic Activity
Prairies	Wheat Granaries Extensive Ranching
Pustaz	Rich black soil Abundant wheat production Sugar from Sugar beet [Beta vulgaris, is a plant whose root contains a high concentration of sucrose] Countries like Hungary, Ukraine, Romania etc.
Pampas	Alfalfa: nutrient rich grass. Ranching, cattle rearing; Dairy products Extensive wheat producing region Economy depends on wheat and beef export
Downs and Canterbury	Sheep and Cattle rearing, Merino sheep: wool production
Veldts	Maize farms Sheep and Cattle rearing

QUESTIONS

Compare and contrast tropical and temperate grasslands in respect of

(a) their seasonal responses to climatic changes
(b) their economic importance

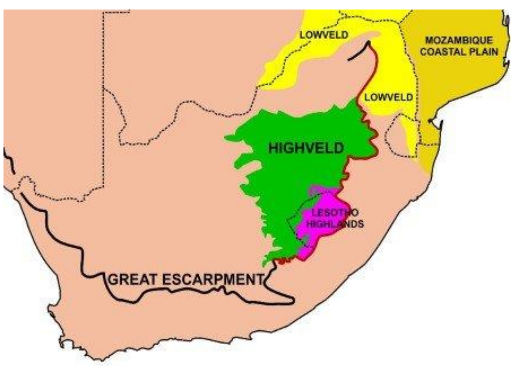
For any three of them, give a reasoned account

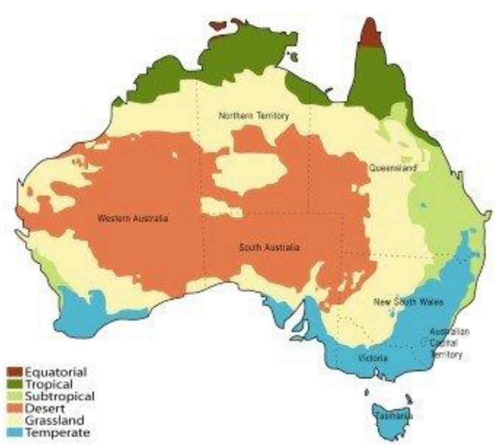
(a) Asiatic Steppes: nomadic herding
(b) Canadian Prairies: spring wheat cultivation
(a) Argentine Pampas: beef cattle ranching
(c) S. African Veld: maize growing
(d) Australian Downs: sheep grazing

Explain why

When Chinooks are more frequent in the Prairies, the winters are milder.

Maps: Savanna Grasslands and Steppe Grasslands



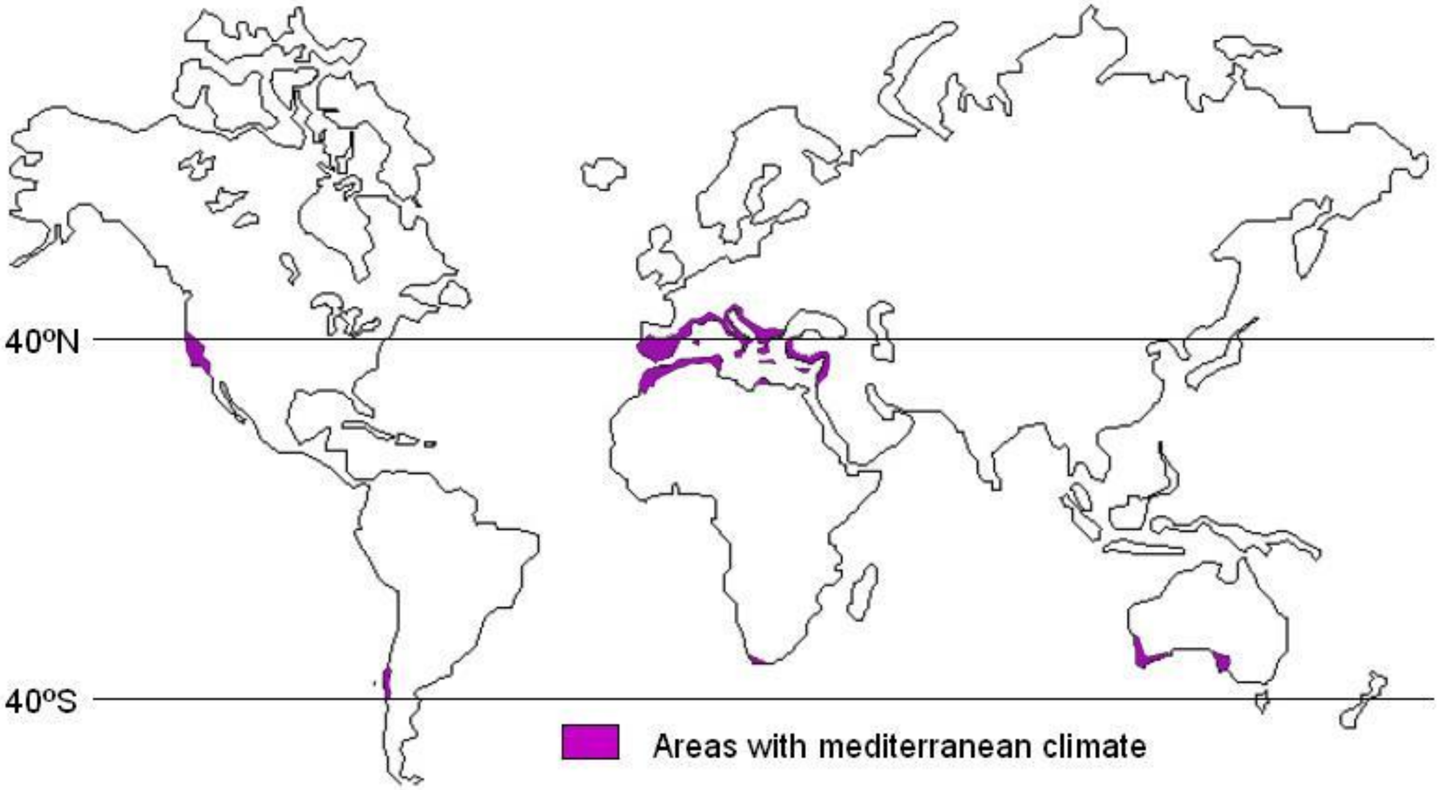


In this post: Mediterranean Climate or Warm Temperate Western Margin Climate or Warm Temperate West Coast Climate, Local winds in Mediterranean Climate, Natural Vegetation in Mediterranean Climate and Agriculture of the Mediterranean Climate.

Mediterranean Climate or Warm Temperate Western Margin Climate or Warm Temperate West Coast Climate

Distribution

- Entirely confined to the western portion of continental masses, between **30° and 45°** north and south of the equator.
- The basic cause of this type of climate is the **shifting of the wind belts**.
- Mediterranean Sea has the greatest extent of this type of ***'winter rain climate'***, and gives rise to the name Mediterranean Climate.
- The best developed form of this climatic type is found in **central Chile.**



- Other Mediterranean regions include

1. **California (around San Francisco),**
2. **the south-western tip of Africa (around Cape Town),**
3. **southern Australia, and south-west Australia (Swanland).**

Mediterranean Climate

Clear skies and high temperatures; hot, dry summers and *cool, wet winters.*

- Mean annual precipitation ranges from **35 - 90 cm.**
- Temperature of warmest month greater than or equal to 10^0 C.
- Temperature of coldest month is less than 18^0 C but greater than -3^0 C
- Climate is **not extreme** because of cooling from water bodies.

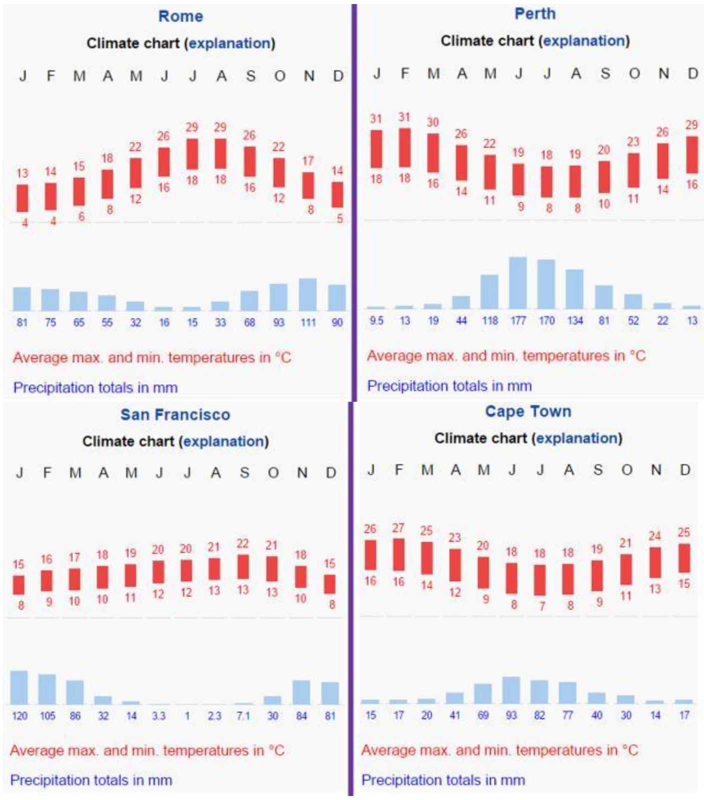
A dry, warm summer with off-shore trades

- In summer when the sun is overhead at the Tropic of Cancer, the belt of influence of the **Westerlies is shifted a little pole wards**. Rain bearing winds are therefore not likely to reach the Mediterranean lands.
- The **prevailing Trade Winds [tropical easterlies] are off-shore** and there is practically no rain.
- Strong winds from inland desert regions pose the risk of wildfires.

Rainfall in winter with on-shore Westerlies

- The Mediterranean lands receive most of their precipitation in **winter** when the Westerlies shift equator wards.
- In the northern hemisphere, the prevailing on-shore Westerlies bring much cyclonic rain from the Atlantic (Typical to Mediterranean Climate).
- The **rain comes in heavy showers and only on a few days with bright sunny periods between them**. This is another characteristic feature of the Mediterranean winter rain.
- Though the downpours are infrequent they are often very torrential and in mountainous districts, **destructive floods** occur.

Climate Graphs



Local winds of the Mediterranean Climate

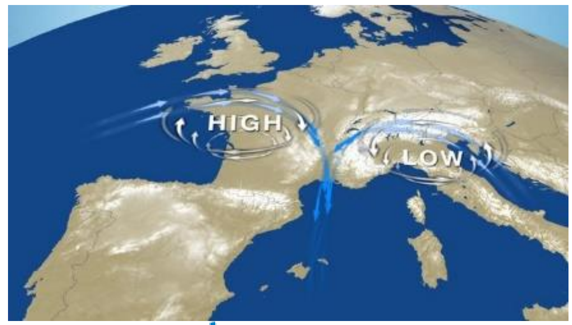
- Many local winds, some hot, others cold are common around the Mediterranean Sea.

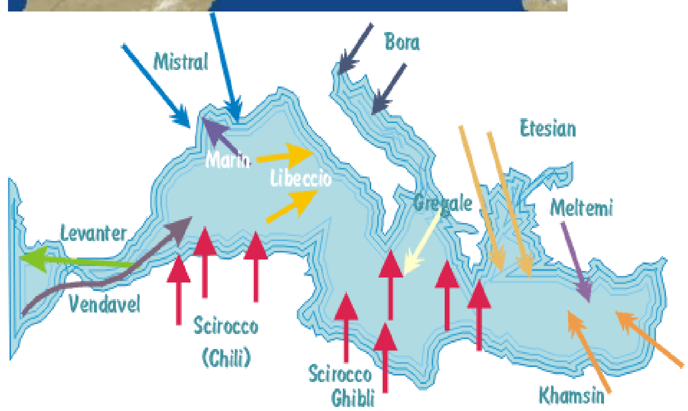
Sirocco

- This is a hot, dry dusty wind which originates in the **Sahara Desert**.
- It is most frequent in **spring** and normally lasts for only a few days.
- The Sirocco blows outwards in a southerly direction (south to north) from the desert interiors into the cooler Mediterranean Sea.
- After crossing the Mediterranean Sea, the Sirocco is slightly cooled by the absorption of the water vapour.
- Its scorching heat withers [To dry up or shrivel from loss of moisture] vegetation and crops.
- This may be **'blood rain'** because the wind is carrying the red dust of the Sahara Desert.

Mistral

- Mistral is a **cold wind** from the north, rushing down the **Rhone valley** in violent gusts between 40 and 80 miles per hour.
- The velocity of the Mistral is intensified by the **funneling effect** in the valley between the **Alps** and the **Central Massif [Plateau in France]**.

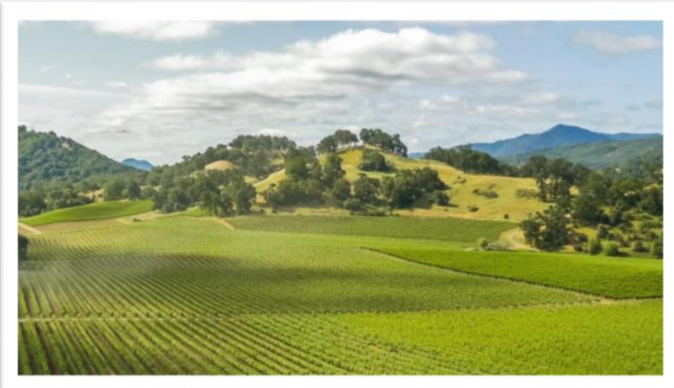




- A similar type of cold north-easterly wind experienced along the **Adriatic coast** is called the **Bora.**
- **Tramontane** and **Gregale** are similar **cold winds** of the Mediterranean Sea.

Natural Vegetation in the Mediterranean Climate

- Trees with **small broad leaves** are widely spaced and **never very tall**.
- The **absence of shade** is a distinct feature of Mediterranean lands.
- Plants are in a continuous struggle against heat, dry air, excessive evaporation and prolonged droughts. They are, in short **xerophytic [drought tolerant]**, a word used to describe the drought-resistant plants in an environment deficient in moisture.



Mediterranean evergreen forests

- These are open woodlands with **evergreen oaks**.
- They are found only in the climatically most favored regions.
- The trees are normally low, even stunted, with massive trunks, small leathery leaves and a wide-spreading root system in search of water.
- The **cork oaks** are specially valued for their thick barks, used for making **wine-bottle corks** and for export around the world.
- In Australia, the **eucalyptus** forests replace the evergreen oak.
- The giant **redwood** is typical of the **Californian** trees.

Evergreen coniferous trees

- These include the various kinds of **pines, firs, cedars** and cypresses which have evergreen, needle-shaped leaves and tall, straight trunks.

Mediterranean bushes and shrubs

- This is perhaps the most predominant type of Mediterranean vegetation.

Grass

- Conditions in the Mediterranean **do not suit grass**, because most of the rain comes in the cool season when growth is slow.
- Even if grasses do survive, they are so **wiry [**lean, tough**] and bunchy** that they are **not suitable for animal farming.**
- Cattle rearing is thus unimportant in the Mediterranean.

Agriculture in the Mediterranean Climate

Orchard farming

- The Mediterranean lands are also known as the **world's orchard lands.**
- A wide range of ***citrus fruits*** such as oranges, lemons, limes, citrons and grapefruit are grown.
- The fruit trees have long roots to draw water from considerable depths during the long summer drought.
- The thick, leathery skin of the citrus fruits prevents excessive transpiration.
- The long, sunny summer enables the fruits to be ripened and harvested.
- The Mediterranean lands account for 70 per cent of the world's exports of citrus fruits.
- The **olive tree** is probably the most typical of all Mediterranean cultivated vegetation.
- Olive oil extracted is a valuable source of cooking oil in a region deficient in animal fat.
- Besides olives, many nut trees like chestnuts, walnuts, hazelnuts and almonds are grown and the nuts picked as fruits or for the chocolate industry.

Crop cultivation and sheep rearing

- **Wheat** is the leading food crop. **Barley** is the next most popular cereal.
- The mountain pastures, with their cooler climate, support a few sheep, goats and sometimes cattle.
- **Transhumance** is widely practiced (moving up and down the hills in search of pastures according to seasons).

Wine production

- **Viticulture** is by tradition a Mediterranean occupation.

- Regions bordering the Mediterranean Sea account for three-quarters of the world's production of wine.
- Some 85 per cent of grapes produced, go into wine.
- The long, sunny summer allows the grapes to ripen.

Economy

Net exporter of citric fruits and net importer of dairy products.

- Clear skies in summer and good landscapes **encourage tourism [Lot of Indian Songs are shot here].**
- European Mediterranean has many ancient cities and are famous for their health and pleasure resorts, frequented by millions all-round the year.

Questions

Give an explanatory account of the following statements about economic activities of the Mediterranean lands.

1. Orchard farming is the predominant occupation.
2. The chief cereal cultivated is hard, winter wheat.
3. Pastoral farming is of little importance.

Write geographical notes on any three of the following.

1. The Mediterranean Climate is typified by dry, sunny summers and wet, mild winters.
2. Hot, dusty Sirocco and cold stormy Mistral.
3. Mediterranean woodlands, shrubs and scrub.
4. Three-quarters of the world's wine comes from the Mediterranean regions of Europe.

A geographic region has the following distinct characteristics: [2010]

1. Warm and dry climate
2. Mild and wet winter
3. Evergreen Oak trees

The above features are distinct characteristics of which one of the following regions?

(a) Mediterranean

(b) Eastern China

(c) Central Asia

(d) Atlantic coast of North America

In this post: Warm Temperate Eastern Margin Climate: Temperate monsoon Climate or China Type Climate, Gulf Type Climate and Natal Type Climate.

Warm Temperate Eastern Margin Climate

- Different variants of Warm Temperate Eastern Margin Climate include the

1. **Temperate monsoon Climate or China Type Climate,**
2. **Gulf Type Climate and**
3. **Natal Type Climate.**

- Found between **20° and 35° N and S latitude** (warm temperate latitudes just outside the tropics); on the **east coast** in both hemispheres.

China Type

- Temperate Monsoon or China Type climate is observed in most parts of China. The climate is also observed in **southern parts of Japan**.

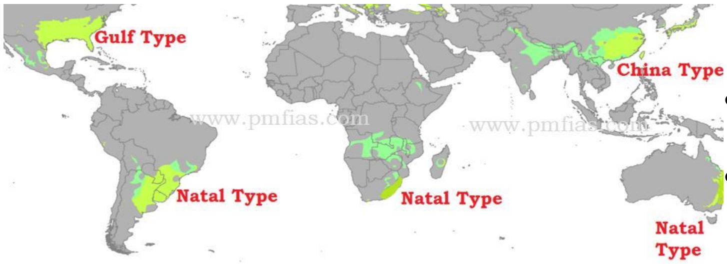
Gulf Type

- Found in **south-eastern U.S.A.**, bordering the Gulf of Mexico where continental heating in summer induces an inflow of air from the cooler Atlantic Ocean.

Natal Type

- Found in in **New South Wales (Australia), Natal (South Africa), Parana-Paraguay-Uruguay basin (South America).**
- Natal type is different from temperate monsoon or China type as it **receives**

rainfall from on-shore Trade Winds all the year round.



Climate

- Characterized by a **warm moist summer** and a **cool, dry winter** (one exception: winters are also moist in Natal Type).

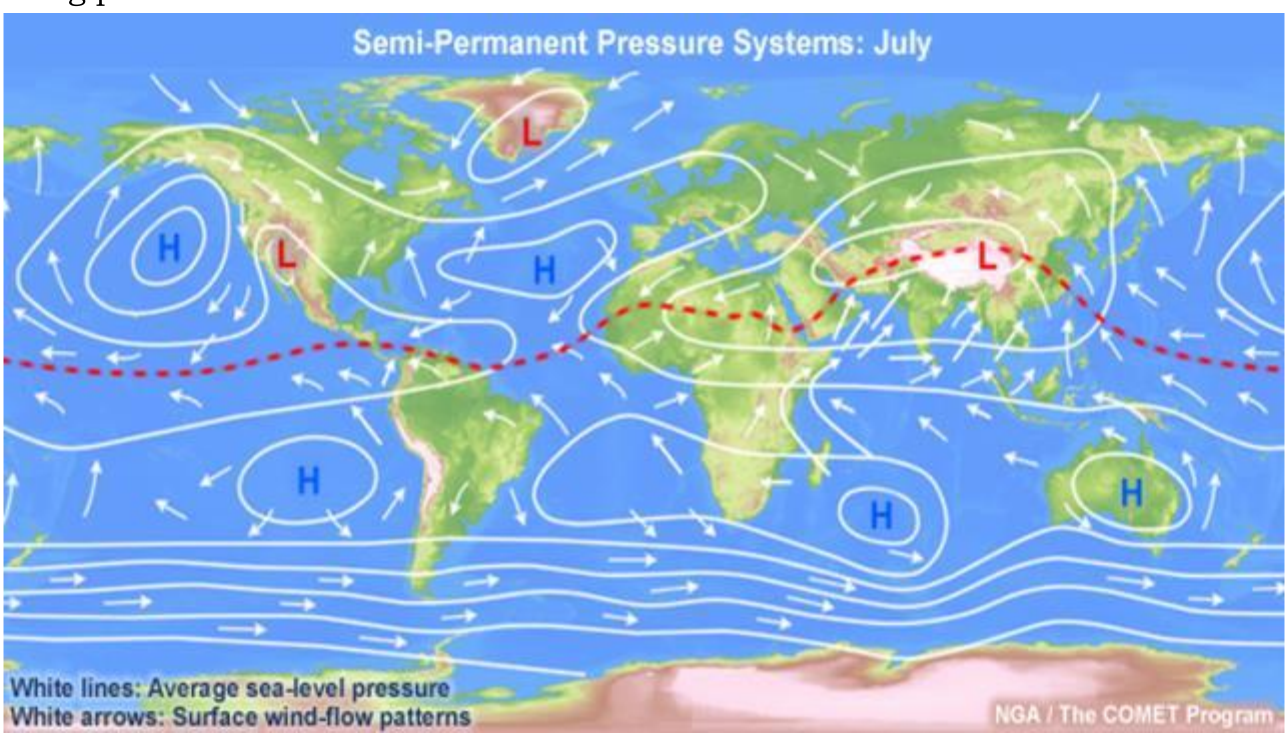
Temperature

- The mean monthly temperature varies between 4° C and 25° C and is strongly modified by **maritime influence.**
- Occasionally, the penetration of **cold air (Polar Vortex)** from the continental interiors may bring down the temperature to freezing point.
- Though frosts are rare they occasionally occur in the colder interiors.

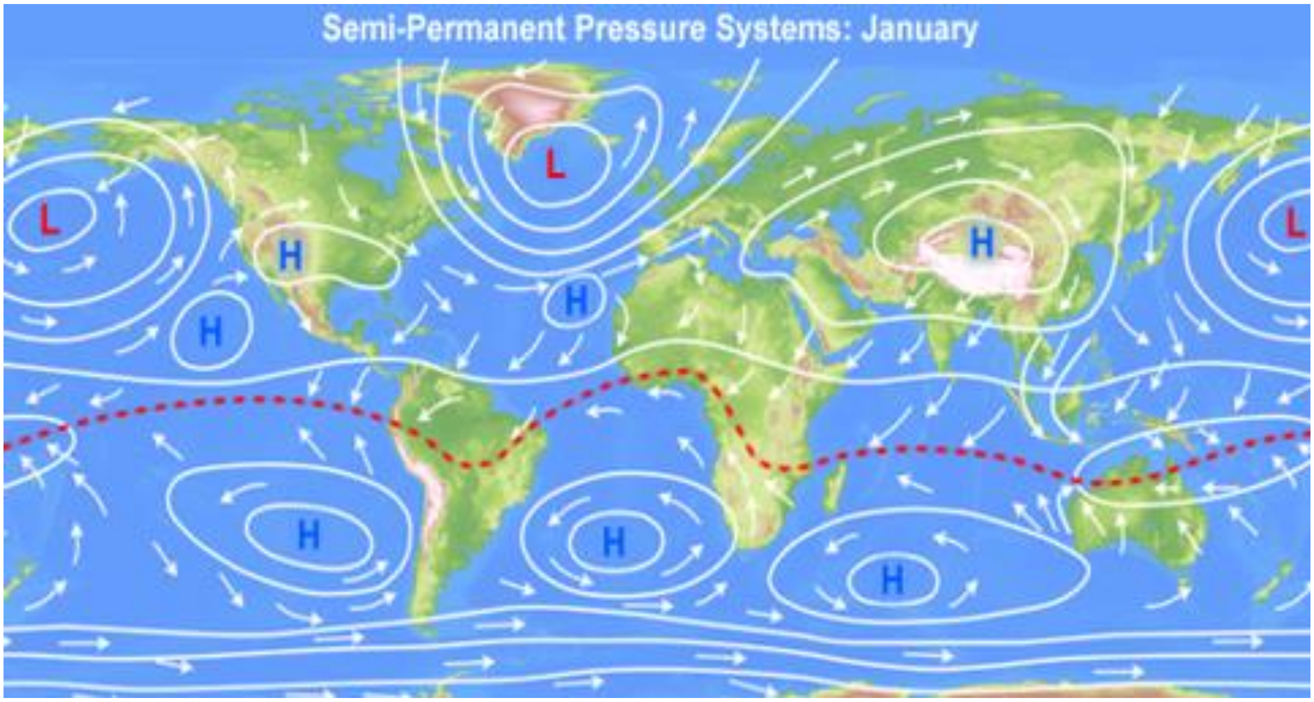
Precipitation

- Rainfall is more than moderate, anything from **60 cm to 150 cm**.
- This is adequate for all agricultural purposes and hence supports a wide range of crops.
- Areas which experience this climate are **very densely populated**.
- There is the **fairly uniform distribution of rainfall throughout the year**.
- Rain comes either from convectional sources or as orographic rain in summer, or from depressions in prolonged showers in winter.
- **In summer, the regions are under the influence of moist, maritime airflow from the subtropical anticyclonic cells.**
- Local storms, e.g. **typhoons (tropical cyclones)**, and **hurricanes**, also occur.

Summer in Northern Hemisphere



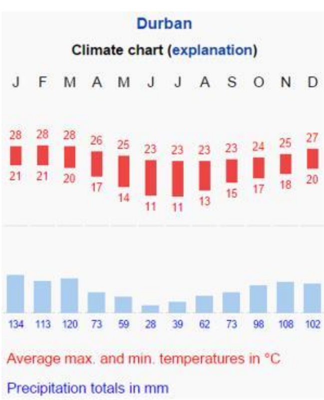
Summer in Southern Hemisphere

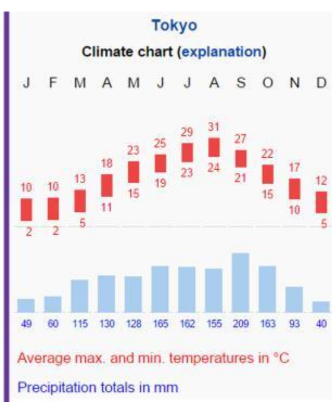


Variations of Warm Temperate Eastern Margin Climate

Climate type	Feature
China type	Temperate monsoonal
Gulf type	Slight-monsoonal
Natal type	Non-monsoonal

Climate Graphs





The China type

Summer

- Intense heating within interiors (Tibet, desert region) sets up a region of low pressure in summer attracting tropical Pacific air stream (South-East Monsoon).
- Monsoon does not 'burst' as suddenly, nor 'pour' as heavily as in India.
- Typhoons form mostly in late summer, from July to September.

Winter

- In winter, there is **intense pressure over Siberia** and the continental polar air stream flows outwards as the North-West Monsoon, bitterly cold and very dry.
- There is little rain but considerable snow on the windward slopes.
- Another climatic feature associated with the China type of climate in southern China is the occurrence of typhoons.

The Gulf type

- Monsoonal characteristics are **less intense** compared to China type.
- There is **no complete seasonal wind reversal**.
- Hurricanes occur in September and October.

The Natal type

- The narrowness of the continents and the dominance of maritime influence **eliminate the monsoonal elements.**

- The South-East Trade Winds bring about a more even distribution of rainfall throughout the year

Natural Vegetation

- Supports a luxuriant vegetation.
- The lowlands carry both evergreen broad-leaved forests and deciduous trees [**hardwood**].
- On the highlands, are various species of conifers such as pines and cypresses which are important **softwoods.**
- Perennial plant growth is not checked by either a dry season or a cold season.

Timber

- The forests of China and southern Japan also have considerable economic value and include oak, camphor, etc..
- South-eastern Brazil, eastern Paraguay, north-eastern Argentina have Parana pine, and the **quebracho** (axe-breaker, an extremely hard wood used for tanning).
- Eastern Australia have Eucalyptus forests.
- In Natal palm trees thrive.
- The Gulf states of U.S.A. have lowland deciduous forests.

Economic Development

Region	Major Cropping Patterns
South-Eastern China	-Rice, tea and mulberries (sericulture) -Sericulture is declining
South-Eastern USA	-Widespread cultivation of maize and cotton in the Corn and Cotton Belts of U.S.A -Fruit and tobacco are also grown
Natal, South Africa	Sugarcane
South America	Coffee and maize and dairying

Farming in monsoon China

- A third of the world's rice is grown in China, though the huge population leaves very little for export.
- Monsoon China has all the ideal conditions for padi cultivation; a warm climate, moderately wet throughout the year, and extensive lowlands with fertile moisture-retentive alluvial soil, which if necessary, can be easily irrigated.
- As the flat lands are insufficient for rice cultivation, farmers move up the hill-slopes and grow padi on terraced uplands.

Agriculture in the Gulf states

- Lack of population pressure and the urge to export gave rise to **corn, cotton and tobacco.**

Corn

- The humid air, the sunny summer and the heavy showers suit the crop well.
- It is grown right from the Gulf coast to the Mid-west south of the Great Lakes, with the greatest concentration in the Corn Belt of Nebraska, Iowa, Indiana and Ohio.
- The region accounts for more than half the world's production of corn, but only 3 per cent of the world's export.
- This is because most of the corn is used for **fattening animals**, mostly **cattle and pigs. [Thriving beef and pork industry]**
- The fattened animals are then sold to the meat plants in Chicago and Cincinnati to be processed into **'corned beef'.** [From here the beef is exported through **Great Lakes** and **St Lawrence** water way]
- Apart from its ease of cultivation, corn's most outstanding feature is its prolific yield.
- It gives almost twice as much food (mainly starch) per acre as wheat or other cereals.
- This explains why it is so widely cultivated in both the warm temperate and the tropical latitudes.

Cotton

- Of the cash crops grown in the Gulf states, none is comparable with cotton.
- The Gulf type of climate is undoubtedly the **best for cotton growing**.
- Its long, hot growing season with 200 days frost free and a moderately high temperature permits the crop to grow slowly and mature within six months.
- In the very south, in the Gulf-lands, the heavy rainfall damages the lint. This area is therefore less suitable for cotton and is devoted to **citrus fruits**, **cane sugar** and **market gardening**, as in Florida.
- The commercial cultivation of cotton is now concentrated only in the most favorable areas which are the **Mississippi flood plains** and **Atlantic coastlands**.
- The most dreaded enemy of the Cotton Belt is the **boll-weevil**. The pest multiplies rapidly. The pest is responsible for the **westward migration of the Cotton Belt**.

Tobacco

- Native crop of America.
- Virginia tobacco is famous.
- The humid atmosphere, the warmth and the well-drained soils of the Gulf states, enable tobacco to be successfully cultivated in many of the eastern states of U.S.A.
- No less than half the tobacco that enters international trade comes from these states.

Crop in Southern Hemisphere

- In the coastlands of Natal, **cane sugar** is the dominant crop, followed by **cotton** and **tobacco** in the interior.
- Maize is extensively cultivated for use both as food and animal fodder for cattle rearing.
- In South America where rainfall is less than 120 cm, there is much grassland on which many cattle and sheep are kept for meat, wool and hides.
- The extensive natural pastures provide valuable forage for both cattle and sheep.
- Further north in southern Brazil, the rainfall increases to more than 120 cm and forest gradually replaces grass.
- Here the important occupations are the cultivation of yerba mate (Paraguay tea) and the lumbering of araucaria or Parana pine. Cattle and sheep are reared, and maize and cane sugar are grown.
- In eastern Australia, Giant eucalyptus trees rise one above the other right up the Eastern Highlands.
- But with the influx of European immigrants, much of the forest has been cleared for settlement and dairying.
- The eastern margin of New South Wales is now the chief source of Australia's milk, butter and cheese, besides cotton, cane sugar and maize which are increasingly grown in the north.

QUESTIONS

Give a reasoned account of any two of the following.

(a) Cotton cultivation in the United States of America.
(b) Padi growing in monsoon China.
(c) Dairying in eastern Australia.
(d) Lumbering in Canada.

Give an explanatory account of any three of the following.

(a) Local storms (e.g. typhoon, hurricane, pampero) are often associated with the Warm Temperate Eastern Margin Climate.
(b) U.S.A. accounts for more than 50 per cent of world production of corn (i.e. maize) but only 3 per cent of world exports.
(c) Farming in monsoon China is usually on a subsistence basis, and the peasants are permanently 'land-hungry'.

In this post: British Type Climate or Cool Temperate Western Margin Climate or North-West European Maritime Climate, Natural Vegetation in British Type Climate and Economy in British Type Climate.

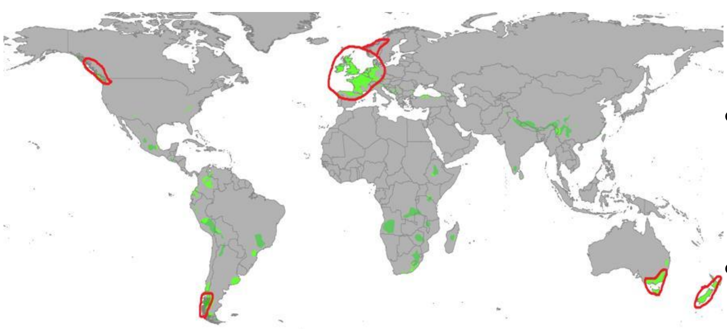
British Type Climate

- Westerlies come all the year round.
- There is a tendency towards an autumn or winter maximum of rainfall.
- Light snow falls in winter.
- Ports are never frozen but frosts do occur on cold nights.
- The seasons are very distinct .
- And the climate is very favorable for maximum human output.

British Type Climate or Cool Temperate Western Margin Climate or North-West European Maritime Climate.

- The cool temperate western margins are **under the influence of the Westerlies all-round the year.**
- They are the regions of **frontal cyclonic activity [Temperate Cyclones]**.
- This type of climate is typical to Britain, hence the name 'British Type'.
- Also called as North-West European Maritime Climate due to **greater oceanic influence.**

Distribution of British Type Climate



Europe

- Most pronounced in and around Britain.
- In Europe the climate extends inland some 2,000 km.
- Climatic belt stretches far inland into the lowlands of North-West Europe (northern and western France, Belgium, the Netherlands, Denmark, western Norway and also north-western Iberia).

North America

- Confined mainly to the coastlands of British Columbia. [high Rockies prevent the on-shore Westerlies from penetrating far inland]

Southern Hemisphere

- The climate is experienced in southern **Chile, Southern Australia, Tasmania** and most parts of **New Zealand.**

British Type Climate

- Moderately warm summers and fairly mild winters.
- **Rainfall occurs throughout the year with winter maxima**.

Temperature

- The mean annual temperatures are usually between 5° C and 15° C.
- Winters are **abnormally mild**. This is because of the warming effect brought by **warm North Atlantic Drift.**
- Sometimes, unusual cold spells are caused by the invasion of **cold polar continental air (Polar Vortex)** from the interiors.

Precipitation

- The British type of climate has **adequate rainfall throughout the year** with a tendency towards a slight **winter maximum (due to frontal cyclones).**
- Western margins have the heaviest rainfall due to westerlies.

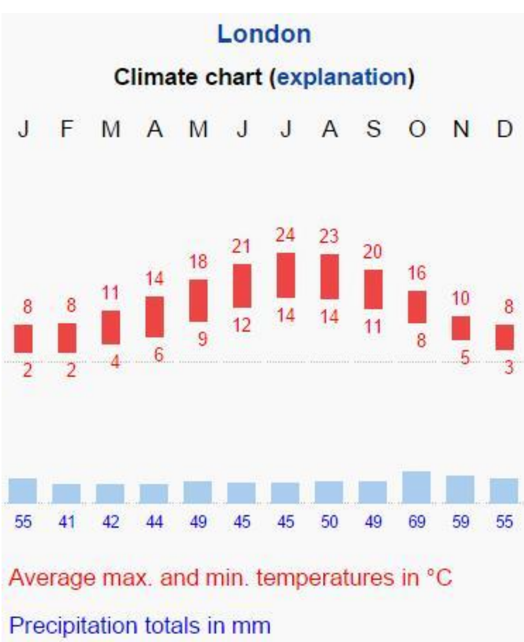
- Relief can make great differences in the annual amount. This is particularly significant in New Zealand where the western margins are subjected to heavy orographic rainfall whereas the eastern

Canterbury plains receive comparatively less rainfall due to **rain-shadow effect.**

The seasons

- As in other temperate regions there are **four distinct seasons**.
- Winter is the season of cloudy skies, foggy and misty mornings, and many rainy days from the passing depressions.
- Spring is the driest and the most refreshing season when people emerge from the depressing winter to see everything becoming green again.
- This is followed by the long, sunny summer.
- Next is the autumn with the roar of gusty winds; and the cycle repeats itself.
- This type of climate with its four distinct seasons is something that is **conspicuously absent in the tropics.** [Rainforest == Only Rainy season, Tropical Monsoon == Summer, Winter and Rainy, Tropical Savanna == Summer (rains) and Winter]

Climate Graph British Type Climate



Natural Vegetation in British Type Climate

- The natural vegetation of this climatic type is **deciduous forest.**
- The trees shed their leaves in the **cold season.**
- This is an adaptation for protecting themselves against the winter snow and frost.
- Shedding begins in **autumn, the 'fall' season**.
- Some of the common species include oak, elm, ash, birch, beech, and poplar.
- In the wetter areas grow willows (Light weight cricket bats are made from willows. In India willows are found in Kashmir).
- Higher up the mountains in the Scandinavian highlands, the Rockies, southern Andes and the Southern Alps of New Zealand, the deciduous trees are generally replaced by the **conifers** which can survive a higher altitude, a lower temperature and poorer soils.

Economy in British Type Climate

Lumbering is quite profitable

- Unlike the equatorial forests, the **deciduous trees** occur in **pure stands** and have greater lumbering value.
- The open nature of the forests with **sparse undergrowth** is useful in logging operations.
- **Easy penetration** means much cost can be saved in the movement of the logs.
- The **deciduous hardwoods** are excellent for both fuel and industrial purposes.
- In Tasmania, the **temperate eucalypts** are also extensively felled for the lumbering industry.
- Higher up the mountains, **conifers (softwood)** are felled and transported to **paper and pulp industry**. They are extensively used in cardboard making.

Industrialization

- The regions are highly industrialized with high standard of living.
- The countries are concerned in the production of machinery, chemicals, textiles and other manufactured articles rather than agriculture, fishing or

lumbering, though these activities are well represented in some of the countries.

- Fishing is particularly important in Britain, Norway and British Columbia.
- Britain, France and Germany have significant mineral resources and are heavily industrialized.
- **Ruhr region in Germany, Yorkshire, Manchester and Liverpool** regions in Britain are significant for wide ranging manufacturing industries.
- Automobile industry is the most significant. (BMW, Volkswagen, Audi, Mercedes-Benz and many other world leading car manufacturers have their headquarters in Germany).
- Industries based on dairy products thrive in **Denmark, Netherlands and New Zealand.**
- Tasmania is important for **merino wool production**. Wool produced here is exported to textile factories in England, Japan, China etc..

Agriculture

- A large range of cereals, fruits and root crops are raised, mainly for home consumption rather than for export.
- North-West Europe, which includes some of the most crowded parts of the globe, has little surplus for export. It is, in fact, a **net importer of food crops, especially wheat**.

Market gardening

- All the north-western European countries are highly industrialized and have high population densities. There will normally be great demand for fresh vegetables, eggs, meat, milk and fruits.
- As the crops are perishable, a good network of transport is indispensable. The produce are shipped by high speed trucks (truck farming, which is commonly used in the United States)
- In Australia, high-speed boats ply across the Bass Strait daily from Tasmania to rush vegetables, tomatoes, apples and beans to most of the large cities in mainland Australia. It is no wonder the Australians nicknamed Tasmania the **'garden state'.**

Mixed farming

- With the rise of industry, more arable farms are being devoured by factories and **wheat is now a net import item in Europe**.
- Throughout north-western Europe, farmers practice both arable farming (cultivation of crops on ploughed land) and pastoral farming (keeping animals on grass meadows).
- Amongst the cereals, wheat is the most extensively grown, almost entirely for home consumption.
- The next most important cereal raised in the mixed farm is **barley**. The better quality barley is sold to the breweries for **beer-making or whisky distilling**.
- The most important animals kept in the mixed farm are cattle.
- The countries bordering the North Sea (Britain, Denmark, the Netherlands) are some of the most advanced dairying countries where cattle are kept on a **scientific and intensive basis.**

Dairying

- The temperate western margin type of climate is almost ideal for **intensive dairying.**
- Cheese is a specialized product of the Netherlands.
- From Denmark and New Zealand comes high-quality butter.
- Milk is converted to cream, which is **less perishable than fresh milk** and is exported to all regions across the globe.
- Fresh milk is converted into various forms of **condensed or evaporated milk**, and exported around the world for baby-feeding, confectionery, ice-cream and chocolate making.

Beef cattle

- Besides dairying, some cattle are kept as beef cattle.
- In Argentina or Australia, meat production is the primary concern.
- The high rate of beef consumption in Europe necessitates large imports of **frozen and chilled beef.**
- The **pigs and poultry** act as **scavengers** that *feed on the left-overs from root-crops and dairy processes.* In this way, Denmark is able to export large quantities of bacon [cured meat from the back or sides of a pig] from pigs that are fed on the **skimmed milk, a by-product of butter-making.**

Sheep rearing

- Sheep are kept both for wool and mutton.
- Britain is the home of some of the best known sheep breeds.
- With the greater pressure exerted on land by increased urbanization, industrialization and agriculture, sheep rearing is being pushed further and further into the less favored areas.
- Britain was once an exporter of wool (But now it imports from Australia). But today exports only British pedigree animals to the **newer sheep lands of the world (Australia).**
- In the southern hemisphere, sheep rearing is the **chief occupation of New Zealand**, with its greatest concentration in the **Canterbury Plain [The rain shadow region]**. It has been estimated that for every New Zealander there are 20 sheep.
- Favourable conditions include extensive meadows, a mild temperate climate, well-drained level ground, scientific animal breeding, the development of refrigeration –enables chilled Canterbury lamb and Corriedale mutton to reach every corner of the globe.
- Though New Zealand has only 4 per cent of the world's sheep population, it accounts for two-thirds of the world's mutton exports, and one sixth of world wool exports.
- In Tasmania and southern Chile, sheep rearing has always been a predominant occupation with surplus sheep products for the international trade.

Other agricultural activities

- Amongst the food crops, **potatoes** feature prominently in the domestic economy of the cool temperate regions.
- It is the staple food in supplementing wheat or bread for millions of people.
- In terms of starch, potato yields far more food than any cereals and can be cultivated over a wide range of climatic and soil types.
- Today almost two-thirds of the world's annual production of potatoes comes from Europe, of which Poland, Germany, France and UK are the major producers.

Beet Sugar

- Found almost exclusively in north-western Europe (including European Russia) and parts of U.S.A.
- The need for such a crop was greatly felt during the Napoleonic Wars around 1800 when military blockades caused a scarcity of sugar.
- The beet is crushed for sugar and the green tops are used as animal fodder.
- The crop thrives best in the warmer and drier east of Britain and in mainland Europe. The highest sugar yield is obtained when the autumn is both dry and sunny.

QUESTIONS

Write a geographical account of the following economic activities.

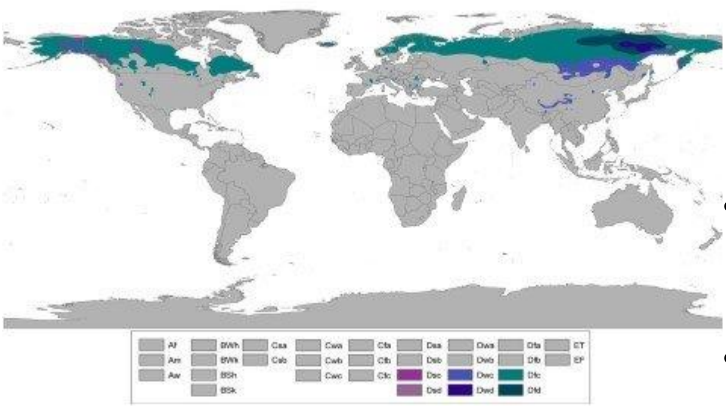
- Mixed farming
- Beet sugar cultivation
- Cool temperate orchard farming
- Sheep rearing
- Woollen textile industry

Give an explanatory account of any two of the following.

- Sheep outnumber the population of New Zealand by 20:1.
- No country produces and exports more wool than Australia.
- Market-gardening is a product of urbanization.

Taiga Climate or Boreal Climate or Siberian Climate or Cool Temperate Continental Climate or Continental Sub-Polar Climate, Natural Vegetation of Taiga Climate, Coniferous forests and Lumbering.

Taiga Climate or Boreal Climate



Boreal Climate OR Taiga Climate OR Siberian Climate OR Cool Temperate Continental Climate OR Continental Sub-Polar Climate.

- Found **only** in the northern hemisphere [due to great east-west extent. Absent in the southern hemisphere because of the narrowness in the high latitudes].
- Experienced in the regions **just below Arctic circle.**
- On its poleward side, it merges into the **Arctic tundra**.
- The climate fades into the temperate **Steppe climate.**

Distribution

- It stretches along a continuous belt across **central Canada**, some parts of **Scandinavian Europe** and most of **central and southern Russian**. **[50° to 70° N]**

Absent in Southern Hemisphere

- Narrowness of the southern continents in the high latitudes is the main reason.
- The **strong oceanic influence** reduces the severity of the winter.
- Coniferous forests are found only on the mountainous uplands of southern Chile, New Zealand, Tasmania and south-east Australia.

Taiga Climate

Temperature

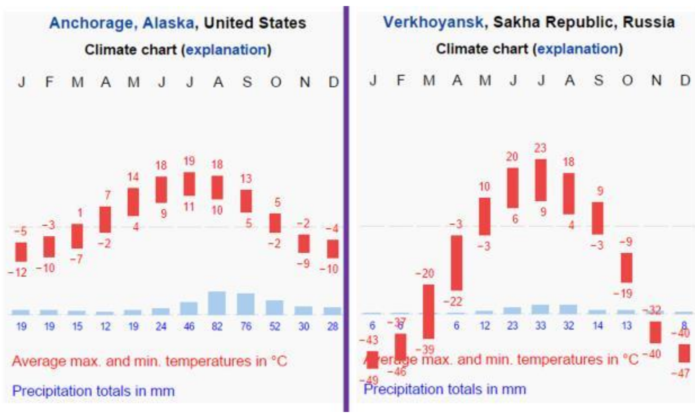
- Summers are brief and warm reaching 20-25 °C whereas winters are long and brutually cold – always 30-40 °C below freezing.
- Annual temperature range of the Siberian Climate is the ***greatest [Almost 50-60 °C in Siberia].***
- Some of the lowest temperatures in the world are recorded in **Verkhoyansk** (68°N. 113°E) where -67 °C was once recorded.
- In North America, the extremes are less severe, because of the continent's lesser east-west stretch.
- All over Russia, nearly all the rivers are **frozen**. In normal years, the Volga is ice-covered for about 150 days.
- Occasionally cold, northerly polar local winds such as the **blizzards of Canada** and **buran of Eurasia** blow violently.
- Permafrosts [a thick subsurface layer of soil that remains below freezing point throughout the year] are generally absent as **snow is a poor conductor of heat** and protects the ground from the severe cold above.

Precipitation

- Maritime influence in the interiors is absent.

- Frontal disturbances might occur in winter.
- Typical annual precipitation ranges from 38 cm to 63 cm.
- It is quite **well distributed throughout the year**, with a **summer maxima** [convectional rain in mid-summer – 15 °C to 24 °C]
- In winter the precipitation is in the form of snow, as mean temperatures are well below freezing all the time.

Climate Graph of Taiga Climate



Natural Vegetation of Taiga Climate

- The predominant vegetation is **evergreen coniferous forest**.
- The conifers, which require little moisture are best suited to this type of sub-Arctic climate.
- The greatest single band of the coniferous forest is the **taiga** (a Russian word for coniferous forest) in Siberia.
- In Europe the countries that have a similar type of climate and forests are **Sweden** and **Finland**.
- There are small amounts of natural coniferous forest in Germany, Poland, Switzerland, Austria and other parts of Europe.
- In North America, the belt stretches from **Alaska** across **Canada** into **Labrador**.

Softwood trees

- The coniferous forest belts of Eurasia and North America are the **richest sources of softwood.**
- Softwood is used in building construction, furniture, matches, **paper and pulp, rayon** and other branches of the chemical industry.
- The world's greatest softwood producers are Russia, U.S.A., Canada and the **Fenoscandian countries (Finland, Norway and Sweden).**
- In the production of **wood pulp** (by both chemical and mechanical methods), the U.S.A. is the leader.
- But in the field of newsprint, **Canada** accounts for almost half of the world's total annual production.
- There are four major species in the coniferous forests – Pine, Fir, e.g. Douglas fir and balsam fir; Spruce and Larch.
- Their presence in **pure stands** and the existence of only a few species are a great advantage in commercial forest exploitation.
- Relatively inaccessible taiga of Siberia will remain the richest reserve of temperate softwood.

Characteristics of Coniferous forests

- Unlike the equatorial rain forests, Coniferous forests are of **moderate density** and are more uniform. The trees in coniferous forests grow straight and tall.
- Almost all conifers are **evergreen**. There is no annual replacement of new leaves as in deciduous trees.
- The same leaf remains on the tree for as long as five years. Food is stored in the trunks, and the bark is thick to protect the trunk from excessive cold.
- Conifers are conical in shape. Their conical shape and sloping branches prevent snow accumulation. It also offers little grip to the winds.
- Transpiration can be quite rapid in the warm summer. So, leaves are small, thick, **leathery** and needle-shaped **to check excessive transpiration.**
- The soils of the coniferous forests are **poor.** They are excessively **leached** and very **acidic**. Humus content is also low as

the evergreen leaves barely fall and the rate of decomposition is slow. Undergrowth is negligible because of the poor soil conditions.

- Absence of direct sunlight and the short duration of summer are other contributory factors.
- Coniferous forests are also found in regions with high elevation [Example: The forests just below the snowline in Himalayas].
- But on very steep slopes where soils are immature or non-existent, even the conifer cannot survive [Example: Southern slopes of Greater Himalayas].

Economic Development of Taiga Region

- Lot of coniferous forests in the northern hemisphere are still untouched due to **remoteness.**
- Only a small fraction of coniferous forests in Canada, Russia etc. are exploited leaving a huge potential for the future.
- More accessible forests are cleared for lumbering on a large scale.
- Agriculture is most unlikely as few crops can survive in the sub-Arctic climates.

Trapping

- Many fur-bearing animals are trapped in northerly lands of Canada and Eurasia.
- Wherever the cold is severe, the quality and thickness of the fur increases.
- The most severe winters produce the finest furs.
- In Canada trappers and hunters, armed with automatic rifles, reside in log cabins in the midst of the coniferous forests to track down these animals.
- Muskrat, ermine, mink, and silver fox are the most important fur-bearing animals.
- To ensure a more regular supply of furs many fur farms have been established in Canada and Siberia.

Lumbering

- This is the **most important occupation** of the Siberian type of climate.
- The vast reserves of coniferous forests provide the basis for the lumbering industry.
- **Lumberjacks:** Contract laborers called lumber jacks used to temporarily move to the forest regions to fell the trees. Now felling is done by machines.
- **Rivers for transportation:** The soft wood logs easily float on rivers. Hence rivers are used to transport logs to the sawmills located down the stream.
- **Sawmilling:** Logs are processed in saw mills into timber, plywood, and other constructional woods.
- **Paper and pulp industry:** Timber is pulped by both chemical and mechanical means to make wood pulp. Wood pulp is the raw material for paper-making and newsprint.
- **Canada and U.S.A**. are leading suppliers of **newsprint** and **wood pulp** respectively.
- **As a fuel:** Very little softwood is burnt as fuel as its industrial uses are far more significant.
- **As an industrial raw material:** In Sweden, matches form a major export item.
- From other temperate countries, timber is used for making furniture, wood- carvings, toys, packing cases etc..
- From the by-products of the timber, many chemically processed articles are derived such as rayon turpentine, varnishes, paints, dyes, liquid resins, wood-alcohols, disinfectants and cosmetics.

Factors that favor lumbering

Coniferous forests is characterized by the following favorable features for Lumbering.

- The conifers are **limited in species**. Pine, spruce and fir in the northern forests and larch in the warmer south are the most important.
- Unlike rainforests, they occur in **homogeneous groups [Pure stands]**. This saves time, costs and enhances the commercial value of the felled timber.

- Lumbering is normally carried out in the winter when the sap ceases to flow. This makes felling much simpler.
- The snow-covered ground makes logging and haulage [commercial transport of goods] a relatively easy job.
- The logs are dragged to the rivers and float to the saw-mills downstream when the rivers thaw [unfreeze] in spring. This has greatly assisted the lumbering industry in eastern Canada and Sweden.
- Lumbering is quite easy in Canada, Norway and Sweden as the rivers are not frozen for a greater part of the year. But in Russian taiga most of Siberian rivers drain poleward into the Arctic Ocean which is frozen for three-quarters of the year, and there are few saw-mills there.
- With the use of the Northern Sea Route, which links Murmansk and Vladivostok via the Arctic Ocean, development is increasing.
- Cheap hydro-electricity for driving the saw-mills is harnessed in the mountainous uplands of North America and Europe and has greatly assisted the lumbering industry.

QUESTIONS

Which one among the following covers the highest percentage of forest area in the world? [2003]

(a) Temperate coniferous forests
(b) Temperate deciduous forests
(c) Tropical monsoon forests
(d) Tropical rain forests

- **Distinguish between hardwoods and softwoods. What industrial uses are made of them? Account for their large scale production for export in any one country.**
- **What is meant by**
  (a) the taiga
  (b) the veld
  (c) the selvas
- **Describe the role played by forest products in the economy of either Canada or Sweden.**

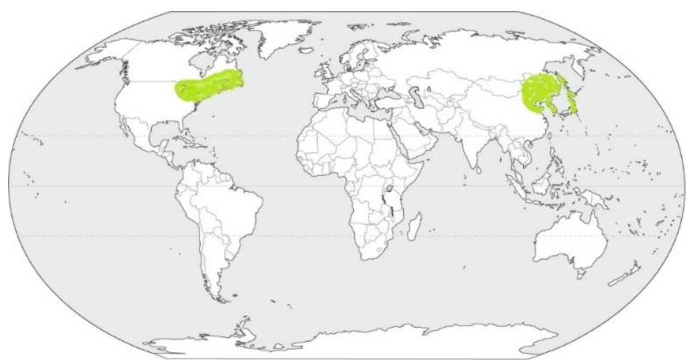
In this post: Laurentian Climate or Cool Temperate Eastern Marine Climate, Natural Vegetation - Laurentian Climate, Economic Development – Laurentian Climate: Fishing in Grand Banks regions (Newfoundland) and Fishing off Japan.

Laurentian Climate or Cool Temperate Eastern Marine Climate

- Intermediate type of climate between the **British Type Climate (moderate)** and the **Taiga Type Climate (extreme)** of climate.
- It has features of **both** the maritime and the continental climates.

Distribution of Laurentian Climate

- Laurentian type of climate is found only in two regions and that too only in the northern hemisphere.



North American region

- North-eastern North America, including **eastern Canada, north-east U.S.A.**, and **Newfoundland**. This may be referred to as the North American region.

Asiatic region

- Eastern coastlands of Asia, including eastern **Siberia, North China, Manchuria, Korea and northern Japan.**

Absent in Southern Hemisphere

- In the southern hemisphere only a small section of continents extends south of 40°S latitude.
- Some of these small sections come under the rain-shadow region of Andes (Patagonia) and hence Westerlies hardly ever reach these regions.
- So these regions are subjected to **aridity** rather than continentiality.
- In other regions, the oceanic influence is so profound that neither the continental nor the eastern margin type of climate exists.

Laurentian Climate

Temperature

- Characterized by **cold, dry winters and warm, wet summers**.
- Winter temperatures is below freezing-point and snow fall is quite natural.
- Summers are as warm as the tropics (~25 °C).

Precipitation

- Rainfall occurs throughout the year with **summer maxima** [easterly winds from the oceans bring rains]
- Annual rainfall ranges from 75 to 150 cm [two – thirds of rainfall occurs in the summer].
- Dry **Westerlies** that blow from continental interiors dominate winters.

The North American region

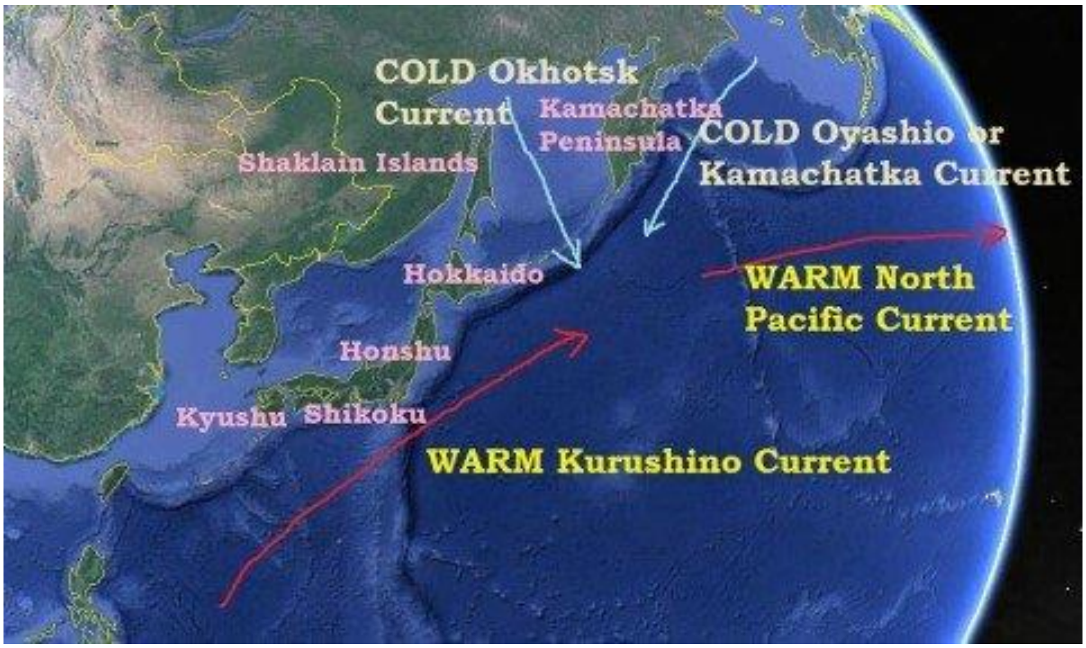
- In summer, prolonged heat waves cause discomfort.
- In winter, the temperature drops below freezing and snowfall occurs.
- Precipitation occurs **all-round the year** due to the influence of **Atlantic ocean (summer)** and the **Great Lakes (winter).**
- The **warm Gulf Stream** increases the moisture of easterly winds.
- The prevailing Westerlies carry depressions over the Great Lakes towards eastern regions causing wet conditions in winter [vital for the agricultural activities].
- Convergence of the warm Gulf Stream and the cold Labrador Current near Newfoundland produces dense mist and fog and gives rise to much precipitation.
- It is said that Newfoundland experiences more **drizzles** than any other part of the world.

The Asiatic region

- Rainfall distribution of the Asiatic region is **far less uniform** when compared to North American Region.
- Winters are cold and **very dry** while summers are very warm and **exceptionally wet**.
- The rainfall regime resembles the **tropical monsoon type** in India.
- Intense heating of the mountainous interior of China in summer creates a region of extreme low pressure, and moisture-laden winds from the Pacific Ocean and the Sea of Japan blow in as the **South-East Monsoon**.
- Thus the Laurentian type of climate in China is often described as the **Cool Temperate Monsoon Climate**.
- It has a very long, cold winter, and a large annual range of temperature.
- Much of the winter precipitation in northern China, Korea and Hokkaido, Japan, is in the form of **snow.**

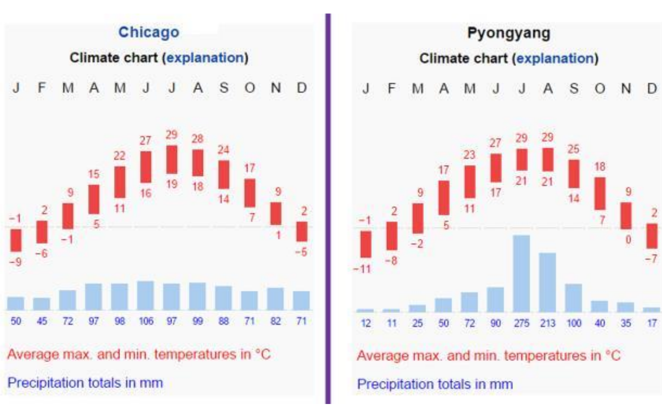
Japan

- The climate of Japan is modified by the **meeting of warm and cold ocean currents.**
- It receives adequate rainfall from both the South-East Monsoon in summer and the North- West Monsoon in winter (western coasts of Japan)
- The **warm Kuroshio** makes the climate of Japan less extreme.
- The meeting zone between **warm Kuroshio** from south and **cold Oyashio** from the north produce fog and mist, making north Japan a **'second Newfoundland'**.



- ***Fishing*** replaces agriculture as the main occupation in many of the **indented coastlands**.

Climate Graph for Laurentian Climate



Natural Vegetation - Laurentian Climate

- The predominant vegetation is **cool temperate forest**.
- The heavy rainfall, the warm summers and the damp air from fogs, all **favor** the growth of trees.
- Forest tend to be **coniferous** north of the 50°N latitude.
- In the Asiatic region (eastern Siberia and Korea), the coniferous forests are a continuation of the great coniferous belt of the taiga.

Lumbering

Timber and **fish** are the leading export items.

Much of the coniferous forests of fir, spruce and larch are exploited to a great extent.

Eastern Canada is the heart of the Canadian timber and wood pulp industry [**St. Lawrence River helps in export**].

South of latitude 50°N., the coniferous forests give way to *deciduous forests*. Oak, beech, maple and birch are most common.

- Almost homogeneous species of trees **[pure stands]**, and the predominance of only a handful of species greatly enhance the commercial value of these forests.
- They have been extensively felled for the extraction of **temperate hardwood.** [From Laurentian Climate regions, both temperate hardwood and temperate softwood are obtained]
- In Manchuria, Korea and Japan, the forests have made way for the **agriculture.**

Economic Development – Laurentian Climate

- Lumbering and its associated **timber, paper and pulp** industries are the most important economic undertaking.
- Agriculture is less important because of long and severe winters.
- In the North American region, farmers are engaged in **dairy farming.**
- The **Annapolis valley in Nova Scotia** is the world's most renowned region for **apples.**
- Fishing is, however, the most outstanding economic activity.

Fishing off Newfoundland

- Regions around the **Grand Banks of Newfoundland** are the **world's largest fishing grounds.**
- Mixing of **warm Gulf Stream** and **cold Labrador currents** make the region the most productive fishing ground on earth.

Fish feed on minute marine organisms called plankton. Plankton is abundantly available in shallow waters [continental shelves] where they have access to both sunlight as well as nutrients. Also, cold and warm water mixing creates upwelling of cold nutrient rich water to the surface.

- The gently sloping continental shelves stretch for over 200 miles south-east of Newfoundland, and off the coasts of the Maritime Provinces and New England.
- Hence microscopic plankton are abundant [Continental Shelf + Mixing of Warm and Cold Ocean Currents].
- Fish of all types and sizes feed and breed here and support a **thriving fishing industry.**
- Along with Canada and U.S.A., countries like Norway, France, Britain, Portugal, Denmark, Russia and Japan, also send fishing fleets to the Grand Banks.
- In Newfoundland, fishing provides employment for almost the entire population.
- Further inland, in lakes and rivers, such as the St. Lawrence and the Great Lakes, freshwater fish, e.g. salmon etc. are caught.
- All the fishing activities are carried out by highly mechanized trawlers which can store fish in refrigerated chambers for months.
- St. John's, chief port of Newfoundland is the headquarters of the Grand Banks fishing industries.
- All processing activities like cutting, cleaning, packing for disposal are done at the ports itself.
- Over-fishing is a growing problem.

Fishing off Japan

- North-west Pacific surrounding the islands of Japan is another very important fishing grounds of the world.
- Majority of the people in the region depend on fishing for survival.
- **Hakodate** and **Kushiro** are large fishing ports with complete refrigeration facilities.
- The Japanese fishing trawlers venture far and wide into the Arctic, Antarctic and the Atlantic waters.
- Large whaling fleets with processing plants venture into distant regions as far as Arctic and Antarctic [**Japan is criticized for its whaling operations**].
- Japan accounts for a sixth of the world's total annual fish caught.
- The Japanese make use of fish wastes, fish meal and seaweeds as fertilizers in their farms.
- Japan is one of the few countries that has taken to seaweed cultivation (India is taking baby steps in seaweed cultivation).
- Coastal farms that are submerged in water grow weeds for sale as fertilizers, chemical ingredient and food.
- Another aspect of Japanese fishing is pearl culture. Pearls are harvested from **pearl oysters**.
- As natural pearls are difficult to obtain in large numbers, so the Japanese have begun to harvest 'cultured pearls'.

Why is fishing the dominant occupation of Japan?

- The mountainous nature of Japan and parts of mainland eastern Asia support little agricultural activity [80 per cent land in Japan is classed as 'non-agricultural'. Around 50% of the total land is covered by forests].
- Japan is not well endowed with natural resources. So, she has to take to the sea if she wants to survive.
- The scarcity of meat (there is little pasture in Japan for livestock farming of any kind) popularized fish as the principal item of diet and the chief protein food of the Japanese and the Chinese as well.
- There exists a great demand for fish and fish products in the nearby countries where fishing industry in under-developed.
- Japan has huge stakes in international fishing enterprises and her advanced fishing techniques give her an edge over competitors.
- Advanced financial services, encouraging government policy, advanced technology at hand, skilled workforce with decades of experience in fishing and the only available natural resource to exploit, make Japan a leader in fishing industry.

Geographical advantage

- The continental shelves around the islands of Japan are rich in plankton, due to the meeting of the warm Kuroshio and the cold Oyashio currents and provide excellent breeding grounds for all kinds of fish.
- The **indented coastline of Japan**, provides **sheltered fishing ports**, calm waters and safe landing places, ideal for the fishing industry.

QUESTIONS

Compare and contrast the climate of the following pairs of areas.

- Laurentian Climate in the North American region and the Asiatic region.
- Tropical monsoon Climate of India and the Warm Temperate Eastern Margin (China type) Climate in S. China.
- The Steppe type of climate in Eurasia and the Siberian type (Taiga climate) of climate in northern Canada.
- The Tundra Climate of Greenland and Trade Wind Desert Climate of central Australia.

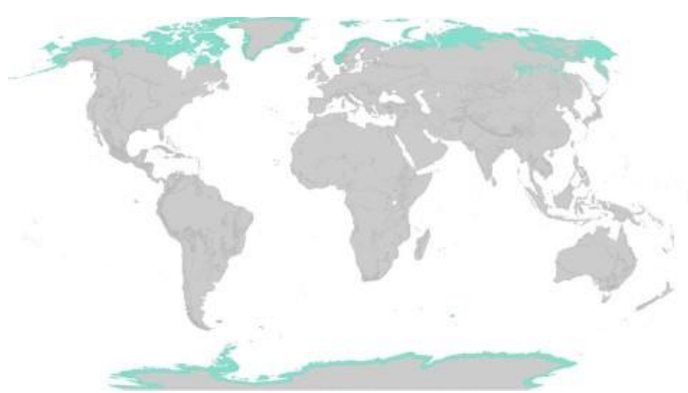
Name the major fishing areas of the world. Explain the geographical factors which have contributed to its importance.

Write brief notes on

- The economy of the forests of the Laurentian regions.
- Fishing in Japan.

In this post: Tundra Climate or Polar Climate or Arctic Climate, Natural Vegetation of Tundra Climate and Development in Tundra Climate.

Tundra Climate or Polar Climate or Arctic Climate



Distribution

- Found in regions **north of the Arctic Circle and south of Antarctic Circle**.
- The ice-caps are confined to highlands and high latitude regions of Greenland and Antarctica.
- In the southern hemisphere, Antarctica is the greatest single stretch of ice-cap (10,000 feet thick).
- The lowlands – coastal strip of Greenland, the barren grounds of northern Canada

and Alaska and the Arctic seaboard of Eurasia, have tundra climate.

Tundra Climate

Temperature

- The tundra climate is characterized by a very **low mean annual temperature**.
- In mid-winter temperatures are as low as 40 – 50 °C below freezing.
- Summers are relatively warmer.
- Normally not more than four months have temperatures above freezing-point.
- Within the Arctic and Antarctic Circles, there are weeks of continuous darkness (Rotation and Revolution).
- The ground remains solidly frozen and is inaccessible to plants.
- Frost occurs at any time and blizzards, reaching a velocity of 130 miles an hour are not infrequent.

Precipitation

- Precipitation is mainly in the form of snow and sleet.
- Convectional rainfall is generally absent.

Natural Vegetation - Tundra Climate

- There are **no trees** in the tundra.
- Lowest form of vegetation like mosses, lichens etc. are found here and there.
- Climatic conditions along the coastal lowlands are a little favorable.
- Coastal lowlands support hardy grasses and the reindeer moss which provide the only pasturage for reindeers.
- In the brief summer, berry-bearing bushes and Arctic flowers bloom.
- In the summer, birds migrate north to prey on the numerous insects which emerge when the snow thaws.
- Mammals like the wolves, foxes, musk-ox, Arctic hare and lemmings also live in tundra regions.
- Penguins live only in Antarctic regions.

Human Activities

- Human activities of the tundra are largely confined to the coast.
- People live a semi-nomadic life.
- In Greenland, northern Canada and Alaska live the **Eskimos.**
- During winter they live in compact **igloos.**
- Their food is derived from fish, seals, walruses and polar bears.
- Now a days rifles instead of traditional harpoons are used to track down animals.

Recent Development of the Arctic Region

- New settlements have sprung up because of the discovery of minerals.
- Gold is mined in Alaska, petroleum in the Kenai Peninsula, Alaska; and copper at the Rankin Inlet, Canada.
- With the declining reserves of iron ore around the Great Lakes, iron ore deposits in Labrador are gaining importance. New railway lines have been constructed to bring the ores to the St. Lawrence River.
- Rich deposits of iron ores at Kiruna and Gallivare helped Sweden enjoy a prosperous export trade in iron and steel and other metallurgical products.
- New ports on the Arctic seaboard of Eurasia has made it possible to ship timber and fur from Siberia. Modern ice-breakers makes the frozen seas navigable.

Oceanography

In this post: Ocean Relief [Ocean Bottom Topography or Relief of the Ocean Floor] – Major Relief features of Ocean Bottom: Continental Shelf, Continental Slope, Continental Rise, Deep Sea Plain or Abyssal Plain, Oceanic Deeps or Trenches and Mid-Oceanic Ridges or Submarine Ridges. Minor Relief features of Ocean Bottom: Abyssal Hills, Submarine Canyons, Atoll, Bank, Shoal and Reef.

Ocean Relief

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

Table 13.1 : Water on the Earth's surface

Reservoir	*Volume (Million Cubic km)*	*Percentage of the Total*
Oceans	1,370	97.25
Ice Caps and Glaciers	29	2.05
Groundwater	9.5	0.68
Lakes	0.125	0.01
Soil Moisture	0.065	0.005
Atmosphere	0.013	0.001
Streams and Rivers	0.0017	0.0001
Biosphere	0.0006	0.00004

Table 13.2 : Components and Processes of the Water Cycle

Components	*Processes*
Water storage in oceans	Evaporation Evapotranspiration Sublimation
Water in the atmosphere	Condensation Precipitation
Water storage in ice and snow	Snowmelt runoff to streams
Surface runoff	Stream flow freshwater storage infiltration
Groundwater storage	Groundwater discharge springs

- Ocean relief features are divided into major and minor relief features.

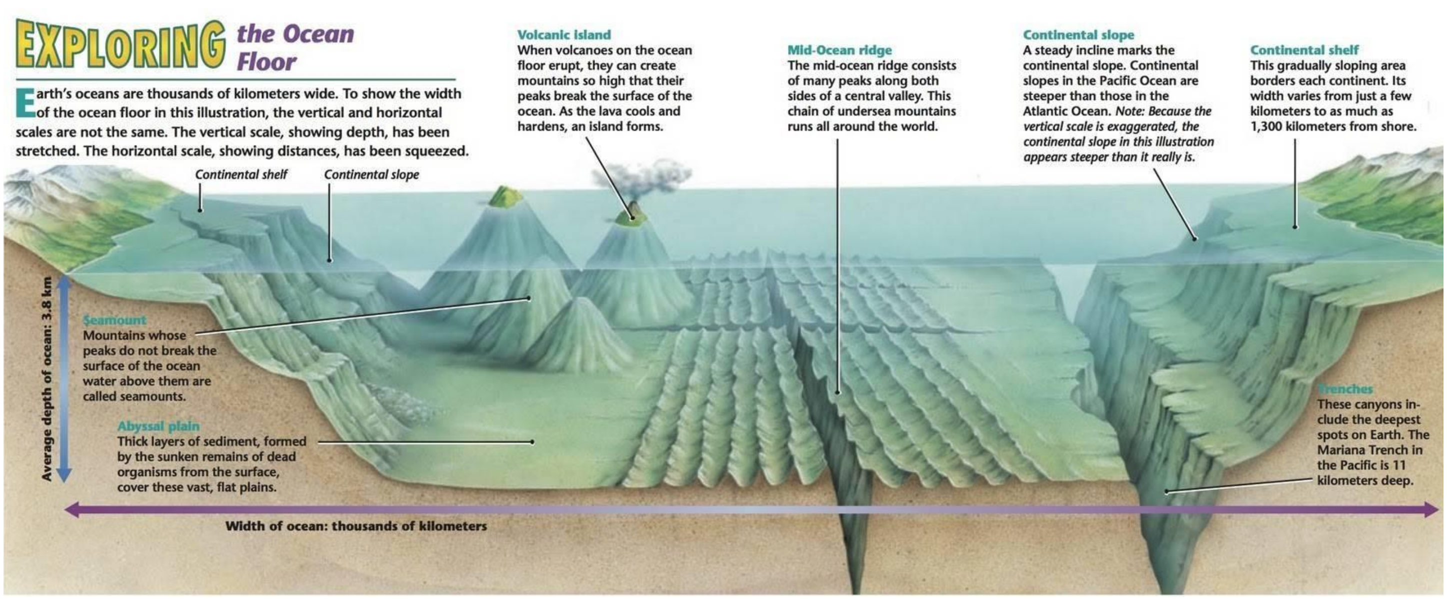
Major Ocean Relief Features

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.**

Minor Ocean Relief Features

- **Ridges,**
- **Hills,**
- **Seamounts,**
- **Guyots,**
- **Trenches,**
- **Canyons,**
- **Sleeps,**
- **Fracture zones,**
- **Island arcs,**
- **Atolls,**
- **Coral reefs,**
- **Submerged volcanoes and**
- **Sea-scarps.**



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].
- Examples: Continental Shelf of South-East Asia, Great Banks around Newfoundland, Submerged region between Australia and New Guinea.
- 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 —

1. **glaciated shelf (Surrounding Greenland),**
2. **coral reef shelf (Queensland, Australia),**
3. **shelf of a large river (Around Nile Delta),**
4. **shelf with dendritic valleys (At the Mouth of Hudson River)**
5. **shelf along young mountain ranges (Shelves between Hawaiian Islands).**

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].
- It is up to 120 km wide along the eastern coast of USA. On the contrary, the **Siberian shelf** in the Arctic Ocean, the largest in the world, stretches to 1,500 km in width.

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.

Importance of continent shelves

1. ***Marine food comes almost entirely from continental shelves;***
2. ***They provide the richest fishing grounds;***
3. ***They are potential sites for economic minerals*** [20% of the world production of **petroleum** and gas comes from shelves. **Polymetallic nodules** (**manganese nodules**; concentric layers of **iron and manganese hydroxides**) etc. are good sources of various mineral ores like manganese, iron copper, gold etc..]

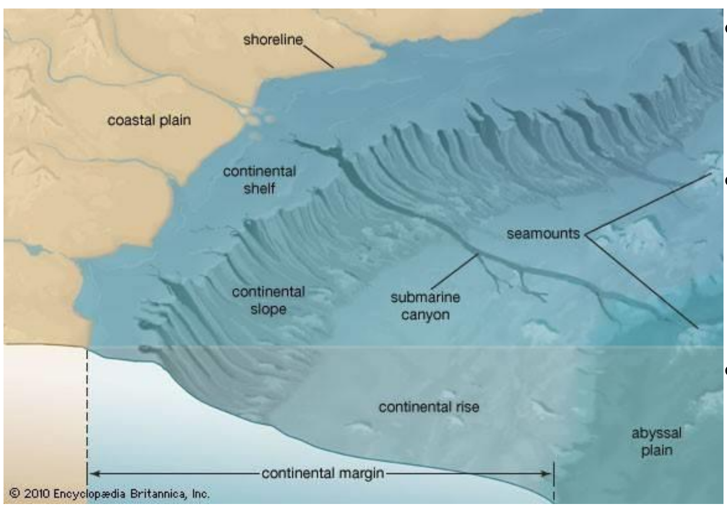
Continental Slope

- 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.

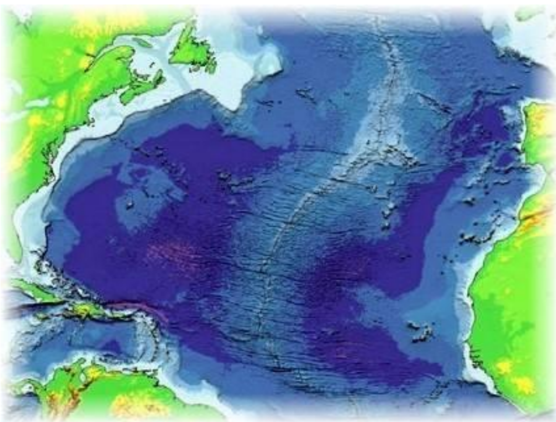
Oceanic Deeps or Trenches

- 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.**
- They are associated with **active volcanoes** and **strong earthquakes** (Deep Focus Earthquakes like in Japan). This makes them very significant in the study of plate movements.
- As many as 57 deeps have been explored so far; of which 32 are in the Pacific Ocean; 19 in the Atlantic Ocean and 6 in the Indian Ocean.

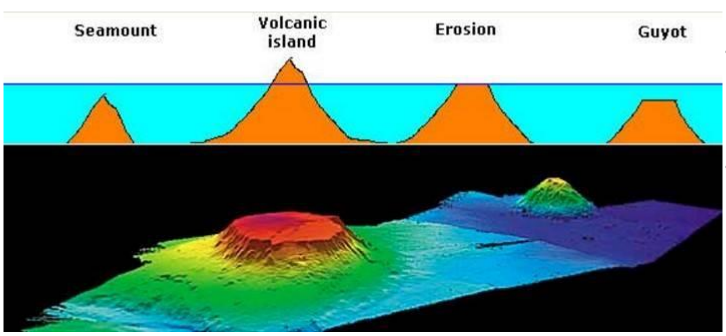
Mid-Oceanic Ridges or Submarine Ridges

- 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.
- Running for a total length of **75,000 km**, these ridges form the **largest mountain systems on earth.**

- These ridges are either broad, like a plateau, gently sloping or in the form of steep-sided narrow mountains.
- These oceanic ridge systems are of **tectonic origin** and provide evidence in support of the theory of **Plate Tectonics.**
- Iceland, a part of the mid-Atlantic Ridge, is an example.



Abyssal Hills



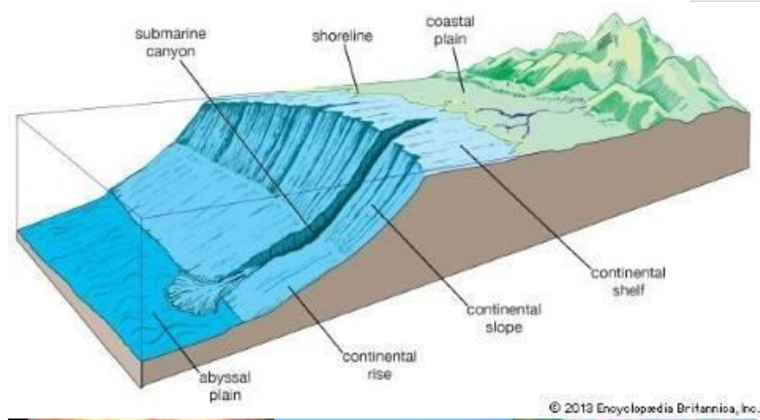
- **Seamount:** It is a mountain with pointed summits, rising from the seafloor that **does not reach the surface** of the ocean. Seamounts are volcanic in origin. These can be 3,000-4,500 m tall.
- The **Emperor seamount**, an extension of the Hawaiian Islands in the Pacific Ocean, is a good example.
- **Guyots:** The flat topped mountains (seamounts) are known as guyots.
- Seamounts and guyots are very common in the Pacific Ocean where they are estimated to number around 10,000.

Submarine Canyons

CANYON: a deep gorge, especially one with a river flowing through it

GORGE: a steep, narrow valley or ravine

VALLEY: a low area between hills or mountains or a depression, typically with a river or stream flowing through it.



- These are deep valleys, some comparable to the Grand Canyon of the Colorado river.
- They are sometimes found cutting across the continental shelves and slopes, often extending from the mouths of large rivers.
- The **Hudson Canyon** is the best known canyon in the world.

Broadly, there are three types of submarine canyons—

- Small gorges which begin at the edge of the continental shelf and extend down the slope to very great depths, e.g., **Oceanographer Canyons** near New England.
- Those which begin at the mouth of a river and extend over the shelf, such as the Zaire, the Mississippi and the **Indus canyons**.
- Those which have a dendritic appearance and are deeply cut into the edge of the shelf and the slope, like the canyons off the coast of southern California. The **Hudson Canyon** is the best known canyon in the world.
- The largest canyons in the world occur in the **Bering Sea** off Alaska. They are the Bering, Pribilof and Zhemchung canyons.

Atoll

- These are low islands found in the tropical oceans consisting of coral reefs surrounding a central depression.
- It may be a part of the sea (lagoon), or sometimes form enclosing a body of fresh, brackish, or highly saline water.

Bank, Shoal and Reef

- These marine features are formed as a result of **erosional, depositional and biological activity.**
- These are produced upon features of **diastrophic [Earth Movements]** origin. Therefore, they are located on upper parts of elevations.

Bank

- These marine features are formed as' a result of erosional and depositional activity.
- A bank is a flat topped elevation located in the continental margins.
- The depth of water here is shallow but enough for navigational purposes.
- The **Dogger Bank** in the North Sea and **Grand Bank** in the north-western Atlantic, Newfoundland are famous examples.
- The banks are sites of some of the most **productive fisheries of the world.**

Shoal

- A shoal is a detached elevation with shallow depths. Since they project out of water with moderate heights, they are **dangerous for navigation.**

Reef

- A reef is a predominantly organic deposit made by living or dead organisms that forms a mound or rocky elevation like a ridge.
- Coral reefs are a characteristic feature of the Pacific Ocean where they are associated with **seamounts and guyots.**
- The largest reef in the world is found off the **Queensland coast of Australia**. [We will study coral reefs in future posts]
- Since the reefs may extend above the surface, they are generally **dangerous for navigation.**

[Coral Bleaching is a very important topic. We will see it later posts]

Significance of Study of Oceanic Relief

- Ocean relief controls the **motion of sea water.**
- The oceanic movement in the form of currents, in turn, causes many variations in both oceans and in atmosphere.
- The bottom relief of oceans also influences **navigation and fishing.**

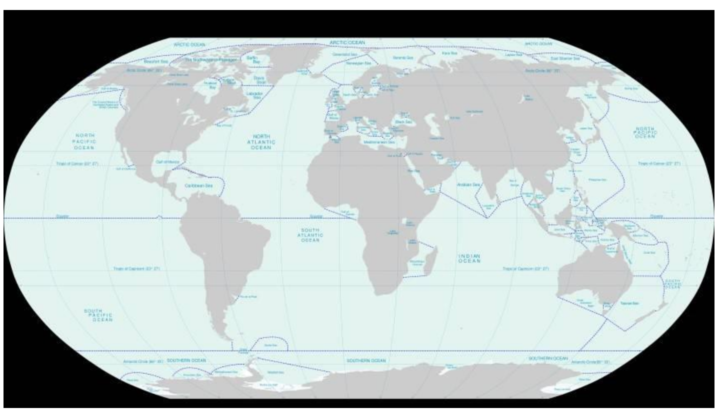
In this post: Marginal Seas, Marginal seas of the world, Human Impact on marginal seas, Phytoplankton Bloom (Algal Bloom) in Marginal Seas, Biomass Production and Primary Productivity, Water Circulation in Marginal Seas, Bay, Gulf, Strait and Isthmus.

Important for Prelims' Environment and Location based questions.

Marginal Seas

- In oceanography, a marginal sea is a sea **partially enclosed** by islands, archipelagos, or peninsulas.
- Some of the major marginal seas include the **Arabian Sea, Baltic Sea, Bay of Bengal, Bering Sea, Black Sea, Gulf of California, Gulf of Mexico, Mediterranean Sea, Red Sea,** and all four of the **Siberian Seas (Barents, Kara, Laptev, and East Siberian).**
- The primary differences between marginal seas and open oceans are associated with depth and proximity to landmasses.
- Marginal seas, which are generally shallower than open oceans, are more influenced by human activities, river runoff, climate, and water circulation.

Important Marginal Seas:



Download the above Image at high resolution: [Very Important Image]

https://drive.google.com/file/d/0B1myJlOn-mMCNWJYSWtMZTItVGM/view?usp=sharing

Marginal seas of the world

- Important marginal seas are mentioned below.

Marginal seas of the Arctic Ocean

- Barents Sea
- The Irish Sea

Marginal seas of the Atlantic Ocean

- Argentine Sea
- Caribbean Sea
- English Channel
- Gulf of Mexico
- Hudson Bay
- Irish Sea
- Labrador Sea
- Mediterranean Sea
- North Sea
- Norwegian Sea
- Scotia Sea

Marginal seas of the Indian Ocean

- Andaman Sea
- Arabian Sea
- Bay of Bengal
- Java Sea
- Persian Gulf
- Red Sea
- Sea of Zanj

Marginal seas of the Mediterranean Sea

Major conflict zones lie on the east of Mediterranean. Also recent refugee crisis is constantly in news. Hence the locations from the region are important for prelims.

- Adriatic Sea
- Aegean Sea

Marginal seas of the Pacific Ocean

- Bering Sea
- Celebes Sea
- Coral Sea
- East China Sea
- Philippine Sea

- Sea of Japan
- Sea of Okhotsk
- South China Sea (another important conflict zone)
- Tasman Sea (between Australia and New Zealand)
- Yellow Sea (by the Korean Peninsula)

Other seas

- The Caribbean Sea is sometimes defined as a marginal sea, sometimes as a Mediterranean sea.
- The Caspian Sea is also sometimes defined as a marginal sea, and also the Dead Sea.

Human Impact on marginal seas

- Marginal seas are **more susceptible to pollution** than open ocean regions because of the high concentration of human activities near coastlines and rivers.
- The greatest human impact on marginal seas is related to the **fisheries industry**.
- Ninety percent of the world's fisheries exist within coastal waters that are located less than 200 kilometers (124 miles) from the shoreline.
- Other human activities that have adversely affected marginal seas include *industrial sewage disposal, offshore oil drilling, and accidental releases of pollutants, including petroleum products, radioactive waste, detergents, and plastics.*
- Pollutants from the nearby landmasses are introduced into marginal seas in concentrations that are thousands of times greater than in open oceans.

Phytoplankton Bloom (Algal Bloom) in Marginal Seas

- The Mediterranean Sea and the Black Sea are marginal seas found in proximity to one another. The color difference shown here is due to a **phytoplankton bloom** occurring in the Black Sea.

- Phytoplankton are good as fish feed on them. But when they proliferate indiscriminately, they **consume too much oxygen during nights**, thus depriving other marine organisms of oxygen.
- For example, the discharge of domestic sewage leads to elevated nutrient concentrations (particularly **phosphates**) which can result in harmful algal blooms.

Biomass Production and Primary Productivity

- Marine biomass production originates with primary productivity, which in turn is affected by the availability of sunlight, carbon dioxide, nutrients such as nitrates and phosphates, and trace elements.
- Marginal seas generally exhibit intermediate levels of primary production, with the **highest rates found in coastal upwelling regions** and the **lowest primary production occurring in open ocean regions**.
- Hence, the highest biomass production rates occur in **coastal upwelling zones**, the **lowest in open oceans regions**, and **intermediate rates in marginal seas**.
- For near shore regions, the dominant processes influencing primary productivity are river runoff, water column mixing, and **turbidity.**
- River runoff and water column mixing introduce dissolved nutrients, trace elements, and suspended particles into

the photic (light) zones of near shore regions.

- Although the addition of dissolved nutrients and trace elements to coastal waters and marginal seas serves to increase primary production, the addition of suspended particles increases water **turbidity**, which results in reduced sunlight penetration and **decreased** primary productivity.

Water Circulation in Marginal Seas

- Water circulation patterns in marginal seas depend largely on shape of the sea, fresh-water input (e.g., river runoff and precipitation) and evaporation.
- If river **runoff and precipitation exceed evaporation**, as is the case in the Black and Baltic Seas, the excess fresh water will tend to flow seaward near the sea surface.
- If evaporation exceeds river runoff and precipitation, as in the Mediterranean Sea, the marginal sea water becomes **saltier**, then sinks and flows towards the less salty open ocean region.

Circulation Patterns in Major Marginal Seas

Black Sea and Baltic Sea

- The Black Sea and Baltic Sea basins both possess **sills** that restrict subsurface water circulation.
- While the surface waters of the Black and Baltic Seas are able to flow over the sills and introduce lower salinity water into the open ocean, the flow of the saltier subsurface waters is blocked by these sills.
- This type of subsurface-water restriction often leads to **stagnation**, which may eventually result in **local oxygen depletion**.

Mediterranean Sea

- The Mediterranean Sea, which is divided by a 400 meter sill into two sub basins, is connected to the Atlantic Ocean via the **Straits of Gibraltar**, to the Black Sea via the **Bosporus Strait**, and to the Red Sea via the **manmade Suez Canal**.
- Atlantic Ocean water enters this marginal sea through the Straits of Gibraltar as a surface flow. This ocean water replaces a fraction of the water that evaporates in the eastern Mediterranean Sea.
- In Mediterranean Sea **evaporation exceeds precipitation** and hence salinity increases.

Gulf of Mexico

- Compared to the Black, Baltic and Mediterranean Seas, the Gulf of Mexico is a much less complex marginal sea.
- The Gulf of Mexico is connected to the Atlantic Ocean via the **Straits of Florida** and the Caribbean Sea via the **Yucatán Strait.**
- In the northern Gulf of Mexico region, Mississippi River runoff influences surface waters as far as 150 meters away from the shore, resulting in salinities as low as 25.
- A unique feature of the Gulf of Mexico's surface circulation pattern is the **Loop Current**, which results from the **Caribbean Current** entering the **Gulf of Mexico** through the **Yucatán Strait** and upon arrival, turning in a clockwise direction and "looping" around a warm "dome" of Gulf of Mexico surface water [More under ocean currents].

Bays, gulfs, and Straits

- Bays, gulfs, and straits are types of water bodies that are contained within a larger body of water near land.
- These three water bodies are usually located at important points of human activities; thus, conflicts with nature and neighbors are common.

Bays

- A bay is a small body of water that is set off from a larger body of water generally where the land curves inward.

- In simple words, bay is a water body surrounded on three sides by land with the fourth side (mouth) wide open towards oceans. (In Gulfs, the mouth is narrow).
- A bay is usually smaller and **less enclosed than a gulf**.
- Example: The Bay of Pigs (Cuba), Hudson Bay (Canada), Bay of Bengal etc.
- An example of a bay at a river's mouth is New York Bay, at the mouth of the **Hudson River (Hudson Estuary).**

Guantánamo Bay

- Guantánamo Bay is a sheltered inlet within the Caribbean Sea.
- During the Spanish-American War in 1898, the United States gained access to the outer harbor of Guantánamo Bay.
- Through an agreement signed with Cuba in 1903, the United States obtained the right to maintain a naval base at Guantánamo Bay.
- In 1934, a treaty reaffirmed the U.S. right to lease the site. The treaty gave the United States a perpetual lease on Guantánamo Bay.
- The most infamous Guantánamo Bay prison is here.

Gulfs

- A gulf is a large body of water, sometimes with a **narrow mouth**, that is almost completely surrounded by land. The world's largest gulf is the **Gulf of Mexico.**
- Examples of other gulfs include the Gulf of California, Gulf of Aden (between the Red Sea and the Arabian Sea), and the Persian Gulf (between Saudi Arabia and Iran).
- The Persian Gulf is important with respect to world energy because petroleum is transported through its waters in oil tankers.

Straits

- A strait is a narrow passageway of water, usually between continents or islands, or between two larger bodies of water.
- The **Strait of Gibraltar** is probably the world's most famous strait. It connects the Atlantic Ocean on its west with the Mediterranean Sea on its east.
- Two other well-known straits are the **Strait of Bosporus** and the **Strait of Hormuz**.
- The Strait of Bosporus connects the **Black Sea (from the north) and the Sea of Marmara (from the south)**, and splits northwestern Turkey.
- The Strait of Hormuz is located at the **southeastern end of the Persian Gulf**. It is a narrow waterway that can be (and has been) controlled to prevent ships from sailing through the gulf.

Choke Point

- When a body of water such as a strait is capable of being blocked or even closed in order to control transportation routes, the body is called a "choke point."
- Historically, the Strait of Gibraltar has been one of the world's most important choke points.
- However, the Strait of Hormuz has become an important choke point in recent years because of increasing Middle East tensions.
- The Strait is surrounded by the United Arab Emirates and Oman (on one side) and Iran (on the other side).

Isthmus

- Isthmus is the land-equivalent of a strait. i.e., a narrow strip of land connecting two larger land masses.
- Example: **Isthmus of Panama** and **Isthmus of Suez.**

In this post: Major Ocean relief: Pacific Ocean - Atlantic Ocean - Indian ocean.

The Pacific Ocean

- Largest and deepest ocean.
- Covers about **one-third** of the earth's surface.
- Average depth is generally around **7,300 metres**.
- Its shape is roughly **triangular** with its apex in the north at the **Bering Strait**.
- Many marginal seas, bays and gulfs occur along its boundaries.
- Nearly 20,000 islands dot this vast ocean.

North and Central Pacific

- Characterized by **maximum depth** and a large number of **deeps, trenches and islands.**
- Some well-known trenches are **Aleutian** and **Kuril**.
- There are also a large number of **seamounts** and **guyots**. [Hawaiian Hotspot]

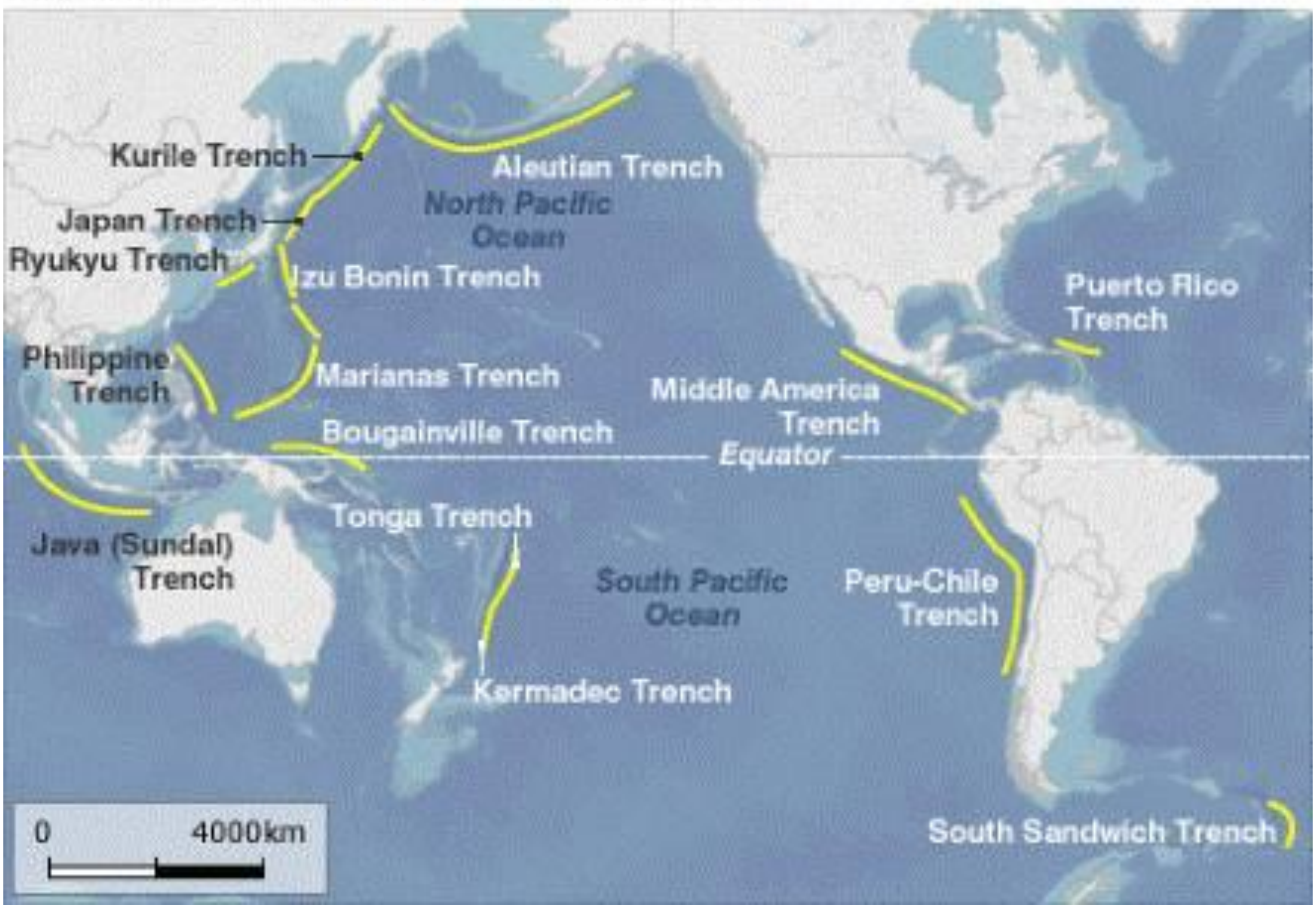
West and South-West Pacific

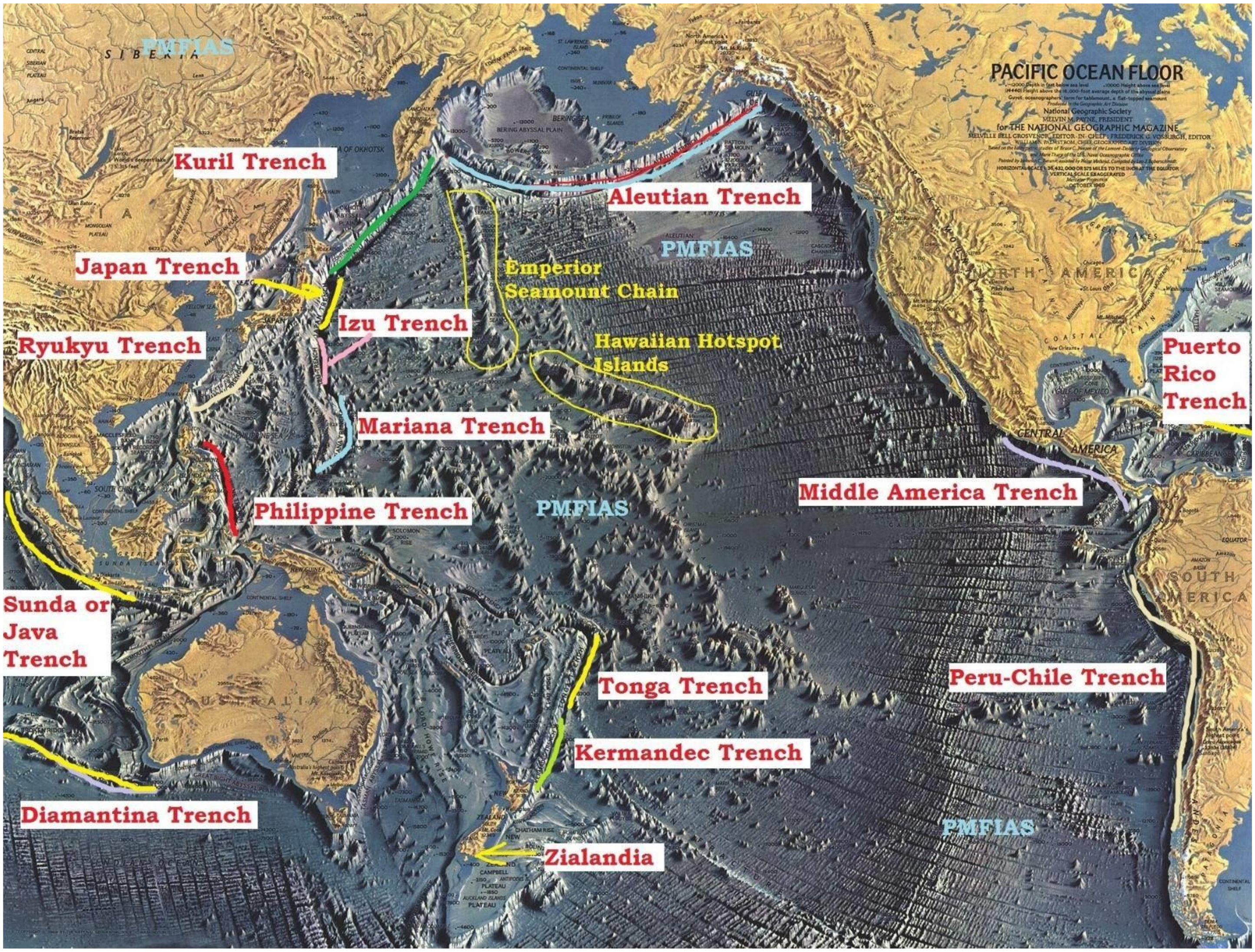
- Average depth is about **4,000 m.**
- It is marked by a variety of islands, marginal seas, continental shelves and submarine trenches.
- **Mariana Trench** and **Mindanao Trench** are very deep with a depth of more than 10,000 metres.

South-East Pacific

- This part is conspicuous for the **absence of marginal seas**, and has submarine ridges and plateaus.
- The **Tonga** and **Atacama** trenches are prominent.

Oceanic Trenches in the Pacific Ocean





The Atlantic Ocean

- The Atlantic is the **second largest** ocean after the Pacific.
- It is roughly **half** the size of the Pacific Ocean.
- It's shape resembles the letter '**S'**.
- In terms of **trade**, it is the most significant of all oceans.

Continental Shelf

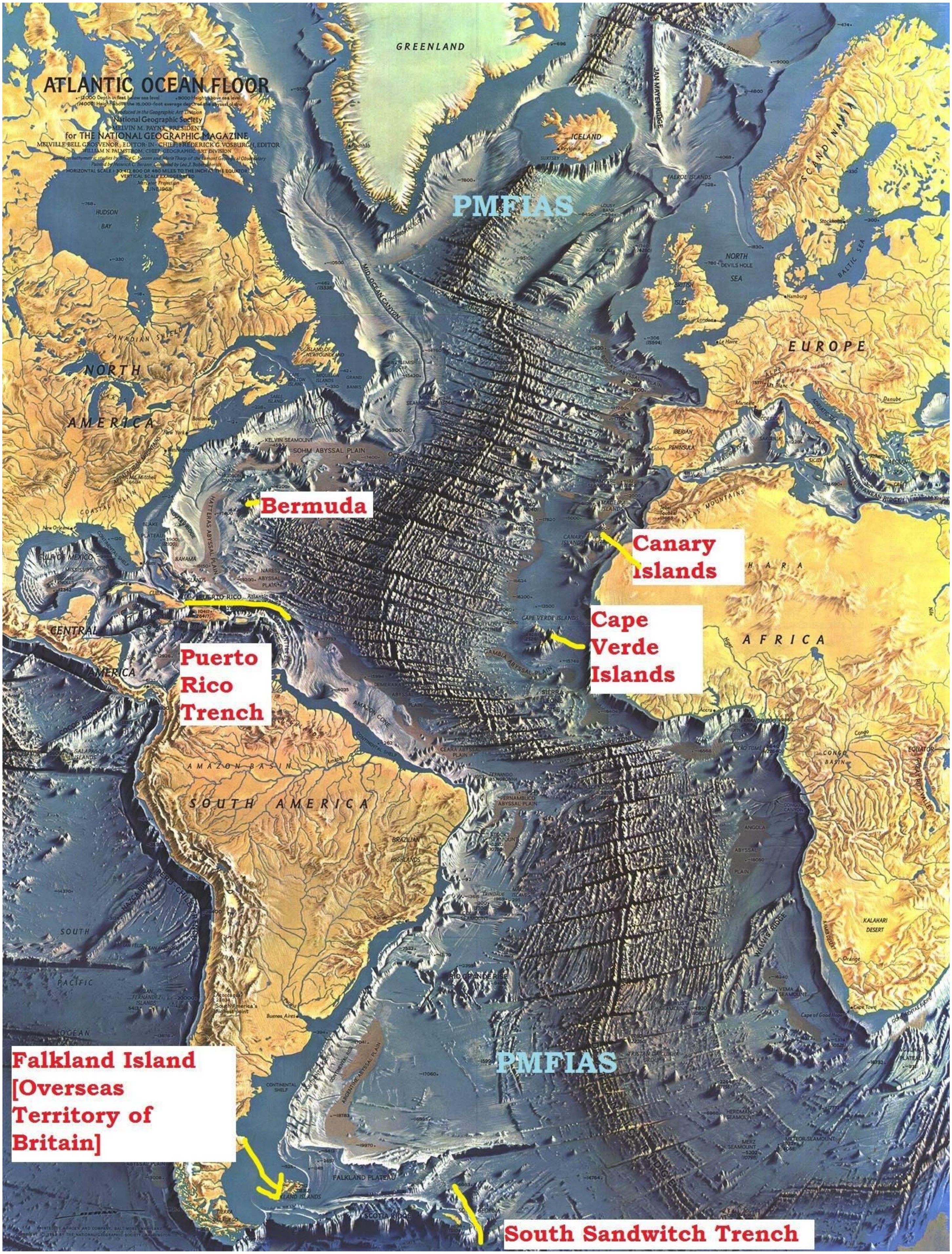
- It has prominent continental shelf with varying widths.
- The length of the continental shelf is maximum in Northern Atlantic coasts.
- The largest width occurring off north-east America and north-west Europe.
- Grand banks continental shelf is the most productive continental shelf in the world. [Recall fishing industry in Laurentian Climate]
- The Atlantic Ocean has numerous marginal seas occurring on the shelves, like the Hudson Bay, the Baltic Sea, and the North Sea, and beyond the shelves like the Gulf of Florida (Mexican Gulf).

Mid-Atlantic Ridge

- The most remarkable feature of the Atlantic Ocean is the Mid-Atlantic Ridge which runs from north to the south paralleling the 'S' shape of the ocean.
- The ridge has an average height of 4 km and is about **14,000 km long.**

Seamounts and guyots

- They are present in significant numbers but not as significant as in pacific ocean.


ATLANTIC OCEAN FLOOR
GREENLAND
ICELAND
PMFIAS
NORTH
AMERICA
EUROPE
Bermuda
Canary Islands
Cape Verde Islands
Puerto Rico Trench
AFRICA
SOUTH AMERICA
PMFIAS
Falkland Island [Overseas Territory of Britain]
South Sandwich Trench

- Several seamounts form islands of the mid-Atlantic. Examples include **Pico Island of Azores, Gape Verde Islands, Canary Islands etc.**.
- Also, there are coral islands like **Bermuda** and volcanic islands like, **St Helena** etc..

Trenches

- Atlantic Ocean **lacks** significant troughs and trenches, which are most characteristic to the Pacific Ocean.
- **North Cayman** and **Puerto Rico** are the two troughs and **Romanche** and **South Sandwich** are the two trenches in the Atlantic Ocean.

The Indian Ocean

- Indian Ocean is the third largest of the world's oceanic divisions.
- Smaller and less deep than the Atlantic Ocean.

Submarine ridges

- Submarine ridges in this ocean include the **Lakshadweep-Chagos Ridge [Reunion Hotspot]**, the **Socotra-Chagos Ridge**, the **Seychelles Ridge**, the **South Madagascar Ridge**, **Carlsberg Ridge etc..**
- These ridges divide the ocean bottom into many basins. Chief among these are the Central Basin, Arabian Basin, South Indian Basin, Mascarene Basin, West Australian and South Australian Basins.

Islands

- Most of the islands in the Indian Ocean are **continental islands** and are present in the north and west.
- These include the Andaman and Nicobar, Sri Lanka, Madagascar and Zanzibar. The **Lakshadweep** and **Maldives** are **coral islands** and **Mauritius** and the **Reunion Islands** are of volcanic origin. The eastern section of the Indian Ocean is almost free from islands

Continental Shelf

- The ocean's continental shelves are narrow, averaging 200 kilometres (120 mi) in width.
- An exception is found off Australia's northern coast, where the shelf width exceeds 1,000 kilometres (620 mi).
- The average depth of the ocean is 3,890 m (12,762 ft).

Trenches

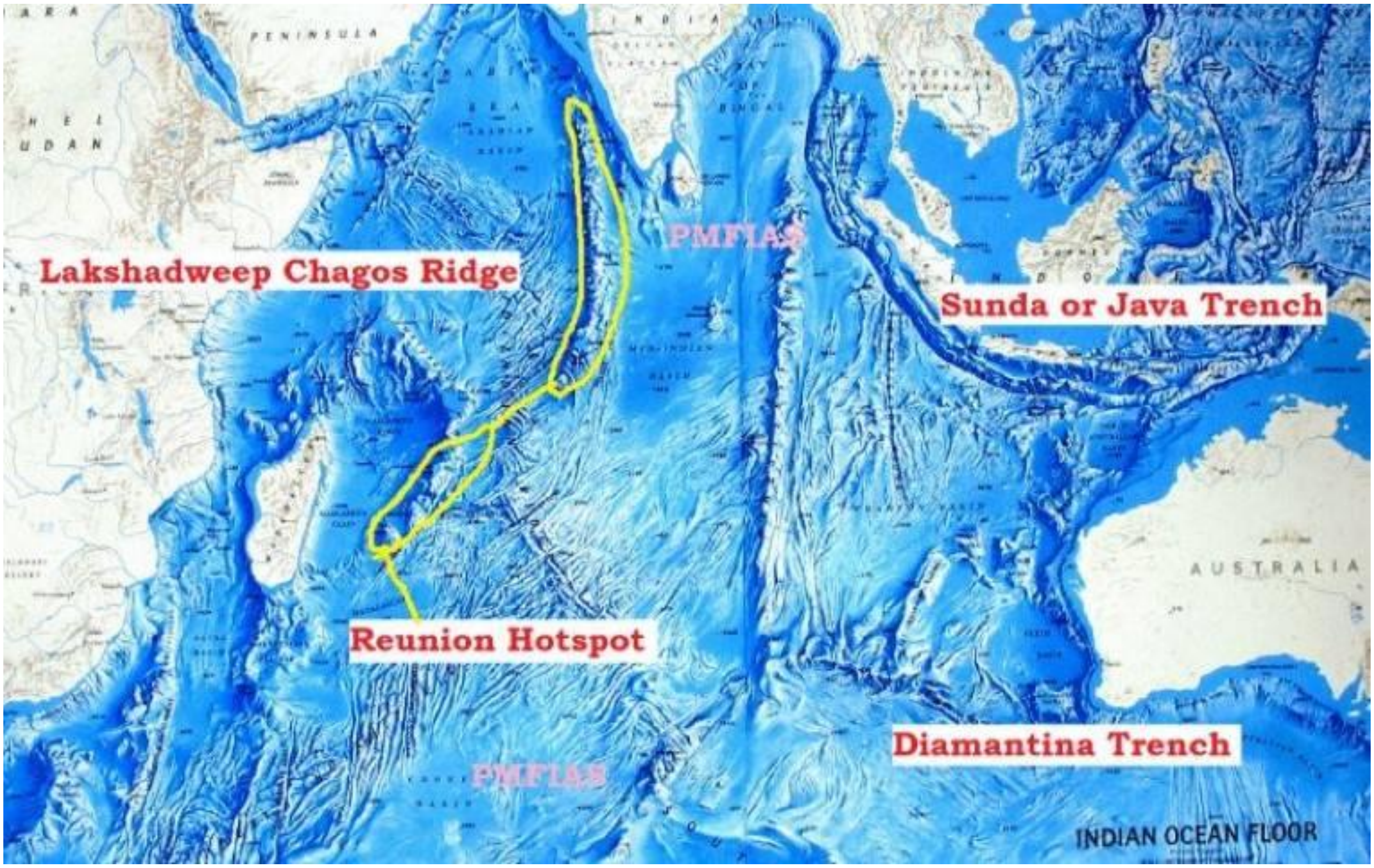
- **Linear deeps are almost absent.** Few exceptions are **Sunda Trench**, which lies to the south of the island of Java and **Diamantina Trench**, west of Australia.
- Its deepest point is **Diamantina Deep in Diamantina Trench**, at 8,047 m. Sunda Trench off the coast of Java is also considerably deep.

Straits

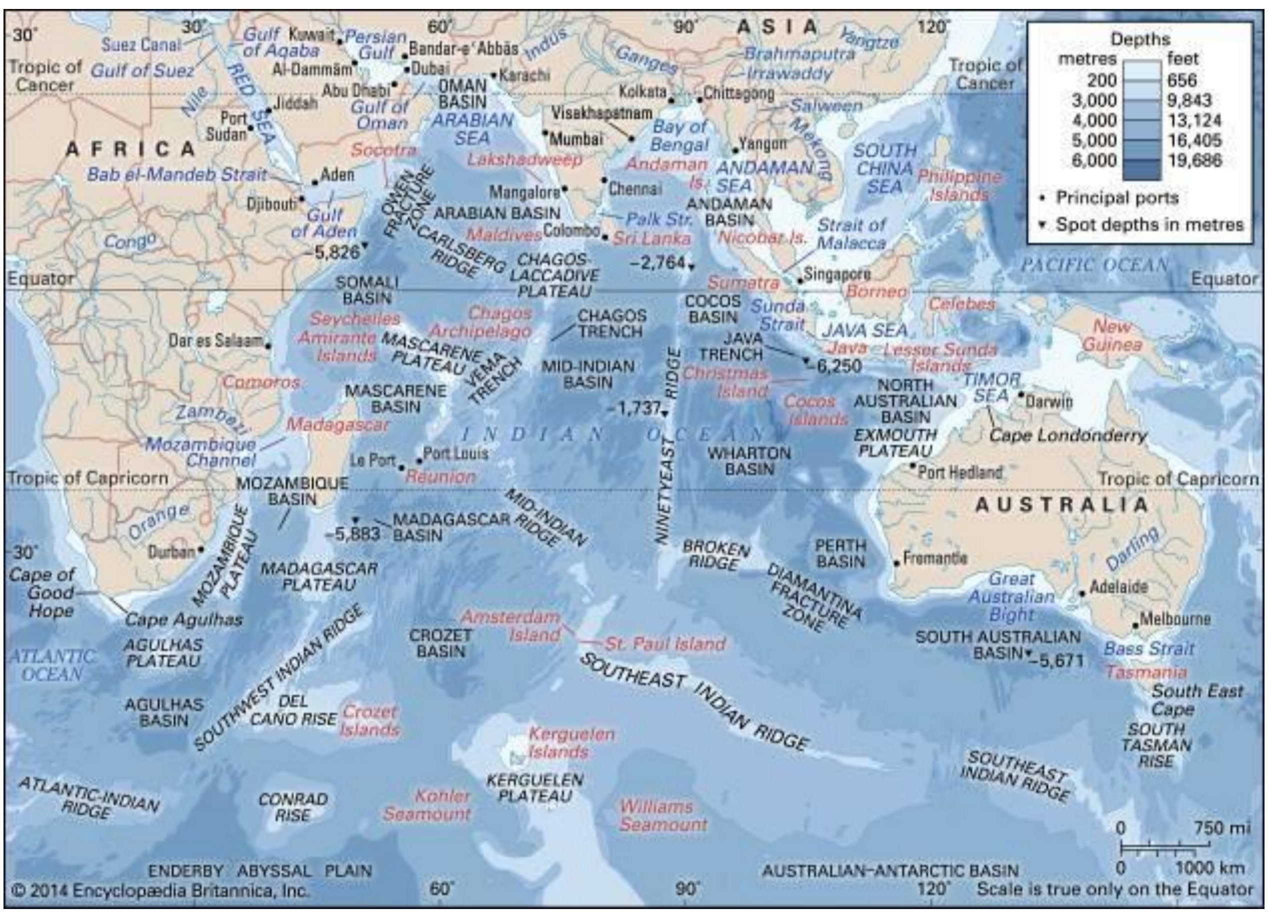
- Most of the straits in Indian Ocean are important trade roots.
- The major choke points include ***Bab el Mandeb***, ***Strait of Hormuz***, the **Lombok Strait**, the ***Strait of Malacca*** and the **Palk Strait**.

Marginal seas

- Arabian Sea
- Persian Gulf
- Red Sea
- Gulf of Oman
- Gulf of Aden
- Strait of Bab-el-Mandeb connecting Arabian Sea
- Gulf of Kutch
- Gulf of Khambat
- Palk Strait connecting Arabian Sea and Bay of Bengal
- Bay of Bengal
- Andaman Sea
- Malacca Strait
- Mozambique Channel
- Great Australian Bight
- Gulf of Mannar
- Laccadive Sea



Lakshadweep Chagos Ridge
PMFIAS
Sunda or Java Trench
Reunion Hotspot
Diamantina Trench
PMFIAS
AUSTRALIA
INDIAN OCEAN FLOOR



ASIA
AFRICA
AUSTRALIA
INDIAN OCEAN
Depths
metres feet
200 656
3,000 9,843
4,000 13,124
5,000 16,405
6,000 19,686
Principal ports
Spot depths in metres
Tropic of Cancer
Equator
Tropic of Capricorn
Suez Canal
Gulf of Suez
Gulf of Aqaba
Kuwait
Persian Gulf
Bandar-e 'Abbās
Al-Dammām
Dubai
Abu Dhabi
Karachi
Indus
Ganges
Brahmaputra
Irrawaddy
Yangtze
Salween
Mekong
Kolkata
Chittagong
Jiddah
Nile
RED SEA
Port Sudan
OMAN BASIN
Gulf of Oman
ARABIAN SEA
Visakhapatnam
Mumbai
Bay of Bengal
Yangon
SOUTH CHINA SEA
Philippine Islands
Socotra
Lakshadweep
Andaman Is.
ANDAMAN SEA
Bab el-Mandeb Strait
Aden
Djibouti
Gulf of Aden
OWEN FRACTURE ZONE
Mangalore
Chennai
ARABIAN BASIN
Palk Str.
ANDAMAN BASIN
Strait of Malacca
Congo
-5,826
CARLSBERG RIDGE
Maldives
Colombo
Sri Lanka
Nicobar Is.
CHAGOS-LACCADIVE PLATEAU
-2,764
Singapore
PACIFIC OCEAN
SOMALI BASIN
Sumatra
Borneo
Celebes
Chagos Archipelago
Seychelles
CHAGOS TRENCH
COCOS BASIN
Sunda Strait
JAVA SEA
New Guinea
Dar es Salaam
Amirante Islands
MASCARENE PLATEAU
VEMA TRENCH
MID-INDIAN BASIN
JAVA TRENCH
Java
Lesser Sunda Islands
-6,250
Comoros
MASCARENE BASIN
Christmas Island
NORTH AUSTRALIAN BASIN
TIMOR SEA
Darwin
Zambezi
Madagascar
-1,737
NINETYEAST RIDGE
Cocos Islands
EXMOUTH PLATEAU
Cape Londonderry
Mozambique Channel
Le Port
Port Louis
Reunion
WHARTON BASIN
Port Hedland
MOZAMBIQUE BASIN
MID-INDIAN RIDGE
Orange
MOZAMBIQUE PLATEAU
-5,883
MADAGASCAR BASIN
Durban
BROKEN RIDGE
PERTH BASIN
Fremantle
Darling
Cape of Good Hope
MADAGASCAR PLATEAU
DIAMANTINA FRACTURE ZONE
Great Australian Bight
Adelaide
Cape Agulhas
Melbourne
AGULHAS PLATEAU
Amsterdam Island
St. Paul Island
SOUTH AUSTRALIAN BASIN
-5,671
Bass Strait
ATLANTIC OCEAN
CROZET BASIN
SOUTHEAST INDIAN RIDGE
Tasmania
SOUTHWEST INDIAN RIDGE
South East Cape
AGULHAS BASIN
DEL CANO RISE
Crozet Islands
SOUTH TASMAN RISE
Kerguelen Islands
SOUTHEAST INDIAN RIDGE
ATLANTIC-INDIAN RIDGE
CONRAD RISE
Kohler Seamount
KERGUELEN PLATEAU
Williams Seamount
0 750 mi
0 1000 km
ENDERBY ABYSSAL PLAIN
AUSTRALIAN-ANTARCTIC BASIN
Scale is true only on the Equator
30° 60° 90° 120°
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In this post: Ocean currents – Factors responsible – Effects.

Next post: Ocean Currents in Pacific Ocean.

Ocean Movements

- TiTBiT: **World Water Day – March 22**
- The movements that occur in oceans are categorized as: **waves, tides and currents.**
- Waves are formed due to **friction** between wind and surface water layer. The stronger the wind, the bigger the wave. They die out quickly on reaching the shore or shallow waters.
- Horizontal currents arise mainly due to **friction** between wind and water. Rotation of earth, Coriolis force and differences in water level gradient also play a major role.
- Vertical currents arise mainly due to density differences caused by temperature and salinity changes.
- Tsunami, storm surge and tides are **tidal waves** [waves with large wavelengths that have greater intensity and destructive power]. Waves and Tides will be dealt in separate posts. For now, we will take a look at ocean currents only.
- Usually temperature distribution and salinity are discussed first. But here, I will begin with ocean currents as they bear a greater influence on both temperature distribution and salinity distribution.

Ocean currents

- Ocean currents are the most important ocean movements because of their **influence on climatology** of various regions. **[Read my previous posts on climatic regions to understand the influence of ocean currents.]**
- 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

Explain the factors responsible for the origin of ocean currents. How do they influence regional climates, fishing and navigation? [Mains 2015]

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

Based on depth

- The ocean currents may be classified based on their depth as **surface currents** and **deep water currents**:

1. surface currents constitute about 10 per cent of all the water in the ocean, these waters are the upper **400 m** of the ocean;
2. deep water currents make up the other 90 per cent of the ocean water. These waters move around the ocean basins due to variations in the density and gravity.

- Deep waters sink into the deep ocean basins at high latitudes, where the temperatures are cold enough to cause the density to increase.

Based on temperature

- 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.

General Characteristics of Ocean Currents

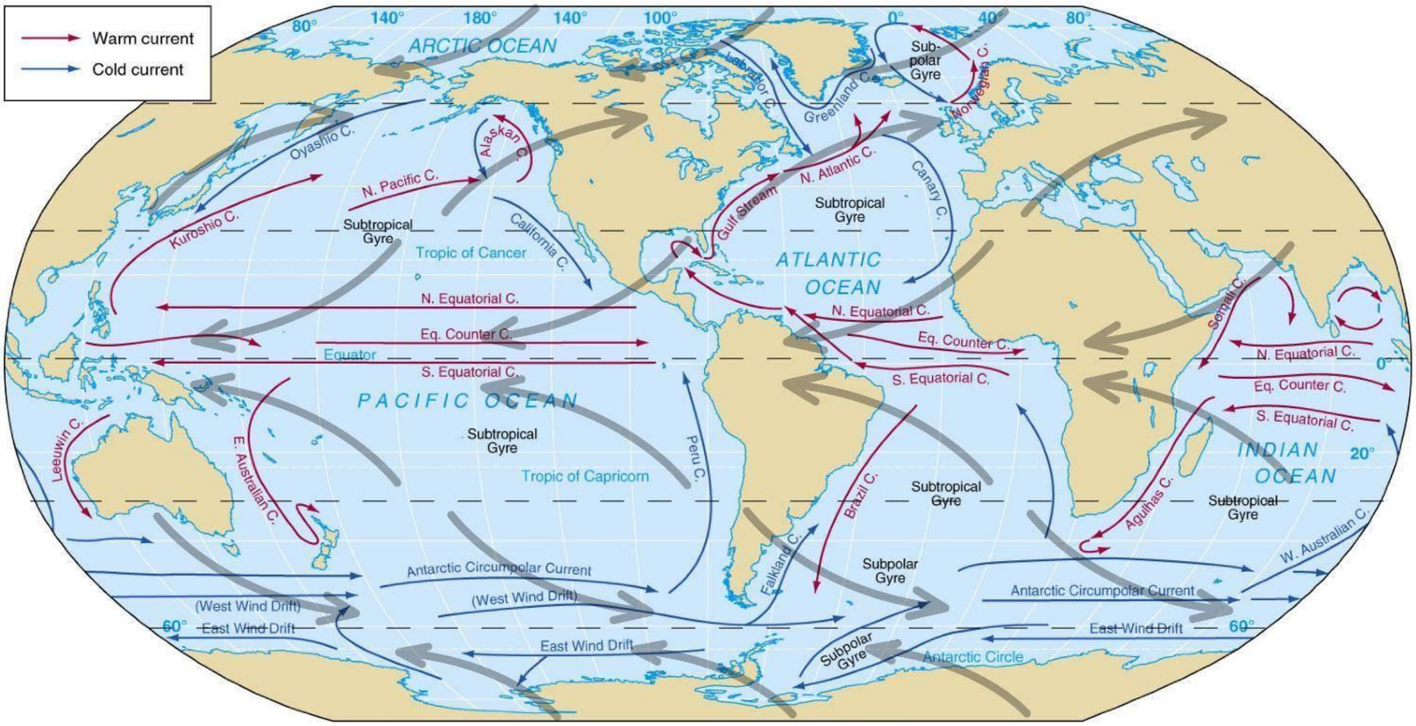
- Characteristics of Ocean Currents arise due to the interplay of the above-mentioned factors.

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 help 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.

Explain the factors responsible for the origin of ocean currents. How do they influence regional climates, fishing and navigation? [Mains 2015]

Desert Formation and Ocean Currents

Major hot deserts are located between 20-30 degree latitudes and on the western side of the continents. Why?

- The aridity of the hot deserts is mainly due to the effects of off-shore Trade Winds, hence they are also called **Trade Wind Deserts.**
- The major hot deserts of the world are located on the western coasts of continents between latitudes 15° and 30°N. and S (Question asked in Previous Mains Exam).
- They include the biggest Sahara Desert (3.5 million square miles). The next biggest desert is the Great Australian Desert. The other hot deserts are the Arabian Desert, Iranian Desert, Thar Desert, Kalahari and Namib Deserts.
- The hot deserts lie along the Horse Latitudes or the Sub-Tropical High

Pressure Belts where the air is descending, a condition least favorable for precipitation of any kind to take place.

- The rain-bearing Trade Winds blow **off-shore** and the Westerlies that are on-shore blow outside the desert limits.
- Whatever winds reach the deserts blow from cooler to warmer regions, and their relative humidity is lowered, making condensation almost impossible.
- There is scarcely any cloud in the continuous blue sky. The relative humidity is extremely low, decreasing from 60 per cent in coastal districts to less than 30 per cent in the desert interiors. Under such conditions, every bit of moisture is evaporated and the deserts are thus regions of permanent drought. Precipitation is both scarce and most unreliable.
- On the western coasts, the presence of cold currents gives rise to **mists and fogs** by chilling the on-coming air. This air is later warmed by contact with the hot land, and little rain falls.
- The **desiccating effect** of the cold Peruvian Current along the Chilean coast is so pronounced that the mean annual rainfall for the Atacama Desert is not more than 1.3 cm.

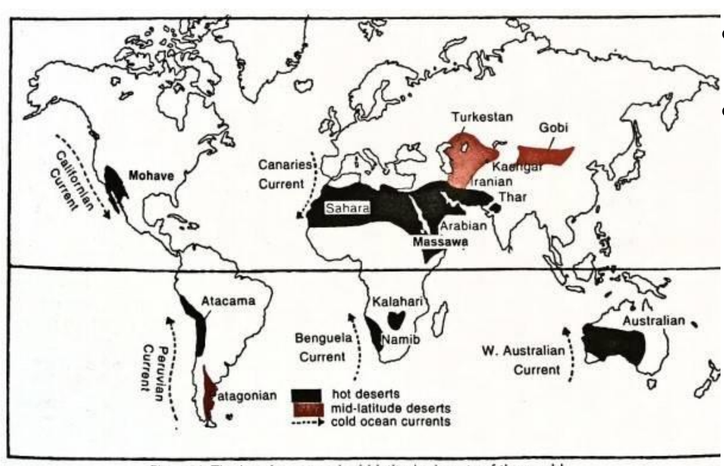


Fig. 131 The hot deserts and mid-latitude deserts of the world

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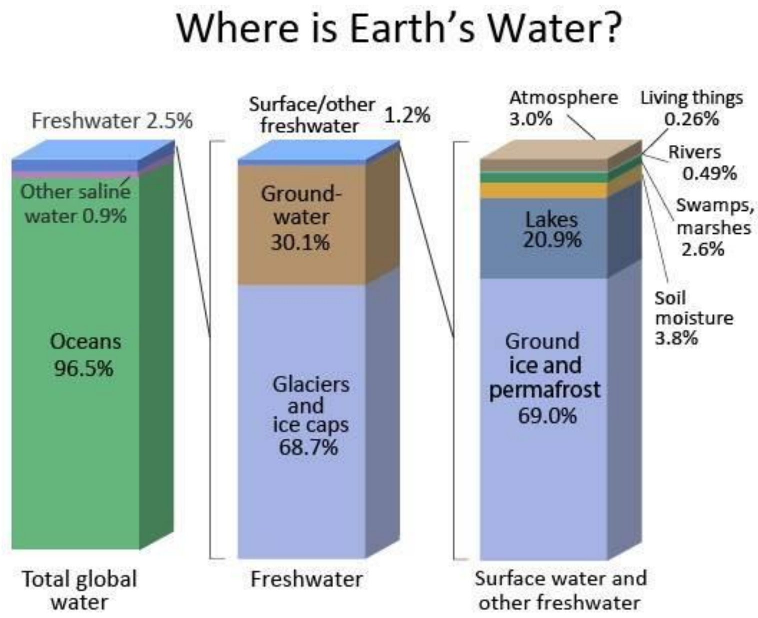
In this post: Temperature Distribution of Oceans – Factors Affecting Temperature Distribution of Oceans, Vertical Temperature Distribution of Oceans, Horizontal Temperature Distribution of Oceans and Range of Ocean Temperature.



Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources.
NOTE: Numbers are rounded, so percent summations may not add to 100.

Temperature Distribution of Oceans

- The study of the temperature of the oceans is important for determining the

1. movement of large volumes of water (vertical and horizontal ocean currents),
2. type and distribution of marine organisms at various depths of oceans,
3. climate of coastal lands, etc.

Source of Heat in Oceans

- The sun is the principal source of energy (Insolation).
- The ocean is also heated by the inner heat of the ocean itself (earth's interior is hot. At the sea surface, the crust is only about 5 to 30 km thick). But this heat is negligible compared to that received from sun.

How does deep water marine organisms survive in spite of absence of sunlight?

- Photic zone is only about few hundred meters. It depends on lot of factors like **turbidity**, presence of algae etc..
- There are no enough primary producers below few hundred meters till the ocean bottom.
- At the sea bottom, there are bacteria that make use of heat supplied by earth's

interior to prepare food. So, they are the primary producers.

- Other organisms feed on these primary producers and subsequent secondary producers.
- So, the heat from earth supports wide ranging deep water marine organisms.

But the productivity is too low compared to ocean surface.

Why is diurnal range of ocean temperatures too small?, Why oceans take more time to heat or cool?

- The process of heating and cooling of the oceanic water is slower than land due to **vertical and horizontal mixing** and **high specific heat of water**.
- (More time required to heat up a Kg of water compared to heating the same unit of a solid at same temperatures and with equal energy supply).

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.

The ocean water is cooled by

1. **Back radiation (heat budget)** from the sea surface takes place as the solar energy once received is reradiated as **long wave radiation (terrestrial radiation or infrared radiation)** from the seawater.
2. **Exchange of heat** between the sea and the atmosphere if there is temperature difference.
3. **Evaporation:** Heat is lost in the form of latent heat of evaporation (atmosphere gains this heat in the form of latent heat of condensation).

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).

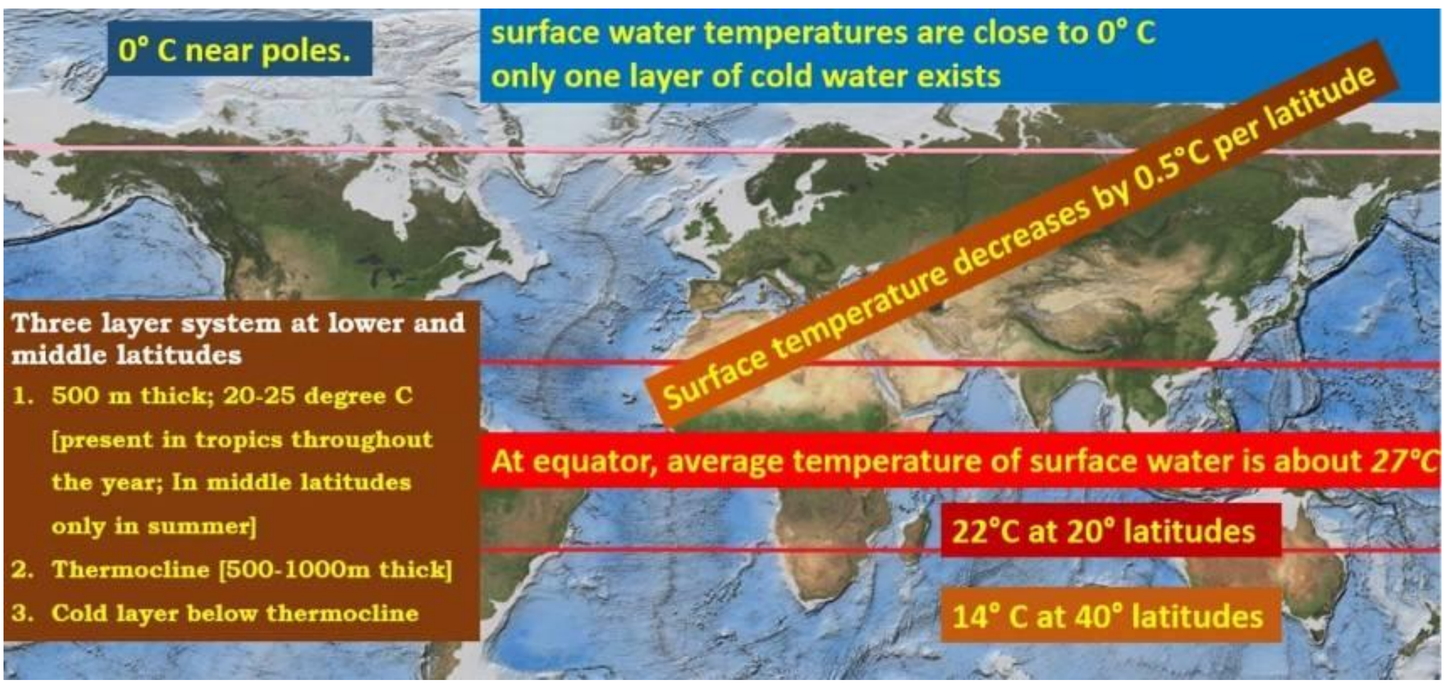
- Contrary to this, the onshore winds (winds flowing from oceans into continents) pile up warm water near the coast and this raises the temperature (This happens near the Peruvian coast during El Nino event)(In normal years, North-eastern Australia and Western Indonesian islands see this kind of warm 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

- **Photic or euphotic zone** extends from the upper surface to ~200 m. The photic zone receives adequate solar insolation.
- **Aphotic zone** extends from 200 m to the ocean bottom; this zone does not receive adequate sunrays.

Thermocline

- The profile shows a boundary region between the surface waters of the ocean and the deeper layers.
- The boundary usually begins around 100 - 400 m below the sea surface and extends several hundred of meters downward.
- This boundary region, from where there is a rapid decrease of temperature, is called the **thermocline**. About 90 per cent of the total volume of water is found below the thermocline in the deep ocean. In this zone, temperatures approach 0° C.



Three-Layer System

- The temperature structure of oceans over middle and low latitudes can be described as a three-layer system from surface to the bottom.
- The first layer represents the top layer of warm oceanic water and it is about 500m thick with temperatures ranging between **20° and 25° C.** This layer, within the tropical region, is present throughout the

year but in mid-latitudes it develops only during summer.

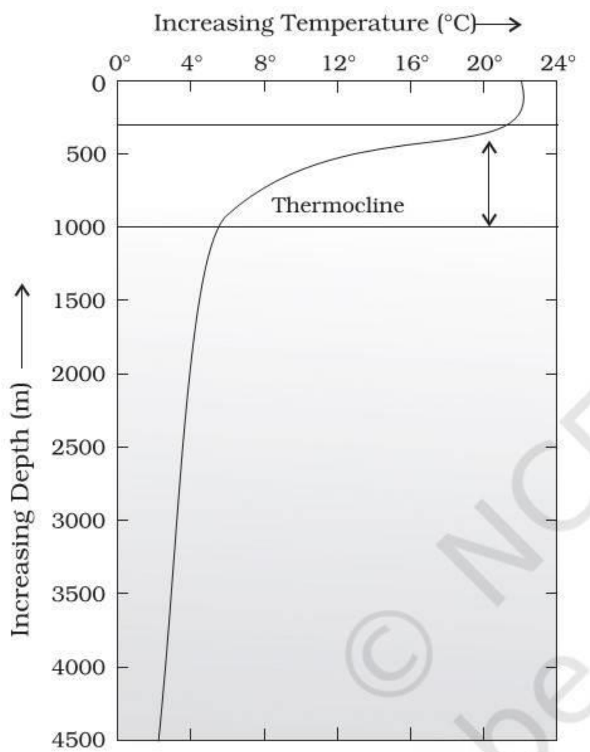


Figure 13.3 : Thermocline

- The second layer called the thermocline layer lies below the first layer and is characterized by rapid decrease in temperature with increasing depth. The thermocline is 500 -1,000 m thick.
- The third layer is very cold and extends up to the deep ocean floor. Here the temperature becomes almost stagnant.

Pycnocline

Pycnocline is a boundary separating two liquid layers of different densities.

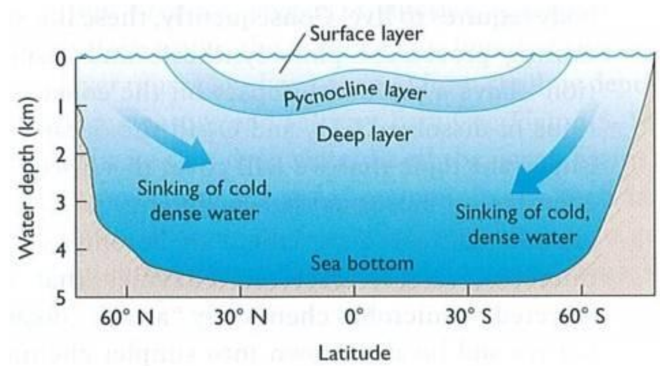
Pycnocline exists in oceans at a depth of 100-1000 m because of large density difference between surface waters and deep ocean water.

Pycnocline effectively prevents vertical currents except in polar regions.

Pycnocline is almost absent polar regions. This is because of the sinking of cold water near poles.

Formation of pycnocline may result from changes in salinity or temperature.

Because the pycnocline zone is extremely stable, it acts as a barrier for surface processes. Thus, changes in salinity or temperature are very small below pycnocline but are seasonal in surface waters.



Similar Terms: **Thermocline, Halocline.**

Thermohaline Circulation

Winds drive ocean currents in the upper 100 meters of the ocean's surface.

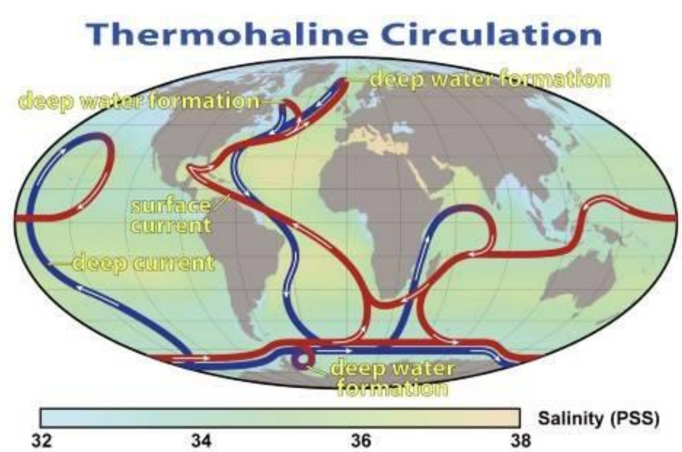
However, ocean currents also flow thousands of meters below the surface.

These deep-ocean currents are driven by differences in the water's density, which is controlled by temperature (thermo) and salinity (haline).

This process is known as thermohaline circulation.

The thermohaline circulation is sometimes called the ocean conveyor belt, the great ocean conveyor, or the global conveyor belt.

Ocean bottom relief greatly influences thermohaline circulation.



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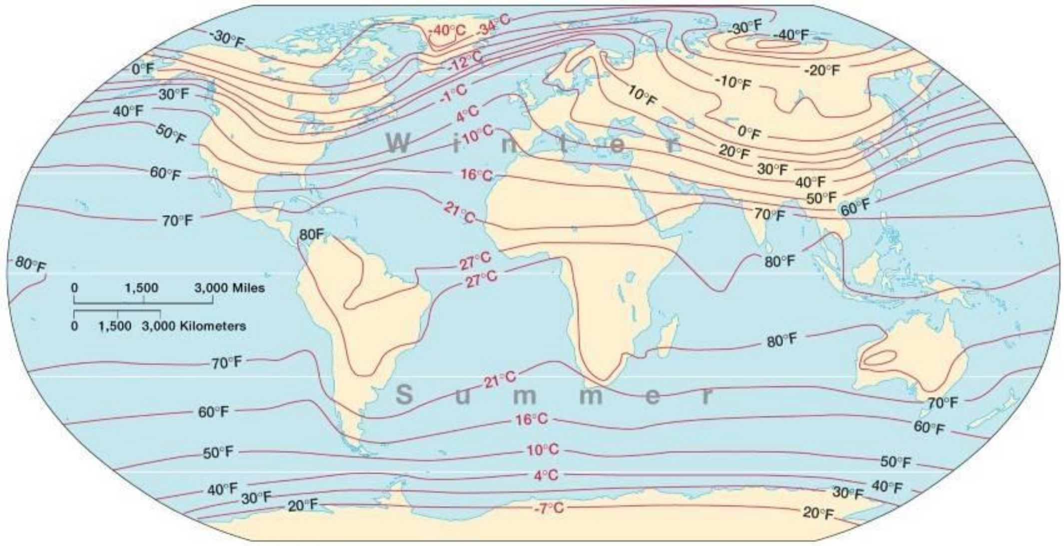
/4/4c/Thermohaline_Circulation_2.png

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.



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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.

Range of Ocean Temperature

- The oceans and seas get heated and cooled slower than the land surfaces. Therefore, even if the solar insolation is maximum at noon, the ocean surface temperature is **highest at 2 p.m.**
- The average diurnal or daily range of temperature is barely 1 degree in oceans and seas.
- The highest temperature in surface water is attained at 2 p.m. and the **lowest, at 5 a.m.**
- The diurnal range of temperature is highest in oceans if the sky is free of clouds and the atmosphere is calm.
- The annual range of temperature is influenced by the annual variation of insolation, the nature of ocean currents and the prevailing winds.
- The maximum and the minimum temperatures in oceans are slightly delayed than those of land areas (the **maximum being in August** and the minimum in February [Think why intense tropical cyclones occur mostly between August and October – case is slightly different in Indian Ocean due to its shape]).
- The northern Pacific and northern Atlantic oceans have a greater range of temperature than their southern parts due to a difference in the force of prevailing winds from the land and more extensive ocean currents in the southern parts of oceans.
- Besides annual and diurnal ranges of temperature, there are periodic fluctuations of sea temperature also. For example, the 11-year sunspot cycle causes sea temperatures to rise after a 11- year gap.

Sunspot

Sunspots are **temporary phenomena** on the **photosphere** of the Sun that appear visibly as dark spots compared to surrounding regions.

They correspond to concentrations of **magnetic field** that inhibit convection and result in reduced surface temperature compared to the surrounding photosphere.

Sunspots usually appear as pairs, with each spot having the opposite magnetic polarity of the other.

Although they are at temperatures of roughly 3,000–4,500 K (2,700–4,200 °C), the contrast with the surrounding material at about 5,780 K (5,500 °C) leaves them clearly visible as dark spots.

Sunspot activity cycles about every **eleven years**. The point of highest sunspot activity during this cycle is known as Solar Maximum, and the point of lowest activity is Solar Minimum.

Pacific Ocean Currents

Previous post: Ocean Currents – Factors Responsible for the Formation of Ocean Currents – Effects of Ocean Currents on climate, fishing, navigation, tropical cyclones.

Equatorial Pacific Ocean Currents

- Under the influence of **prevailing trade winds [tropical easterlies]**, the **north equatorial current** and the **south equatorial current** start from the eastern pacific (west coast of Central America) and traverses a distance of 14,500 km moving from **east to west.**

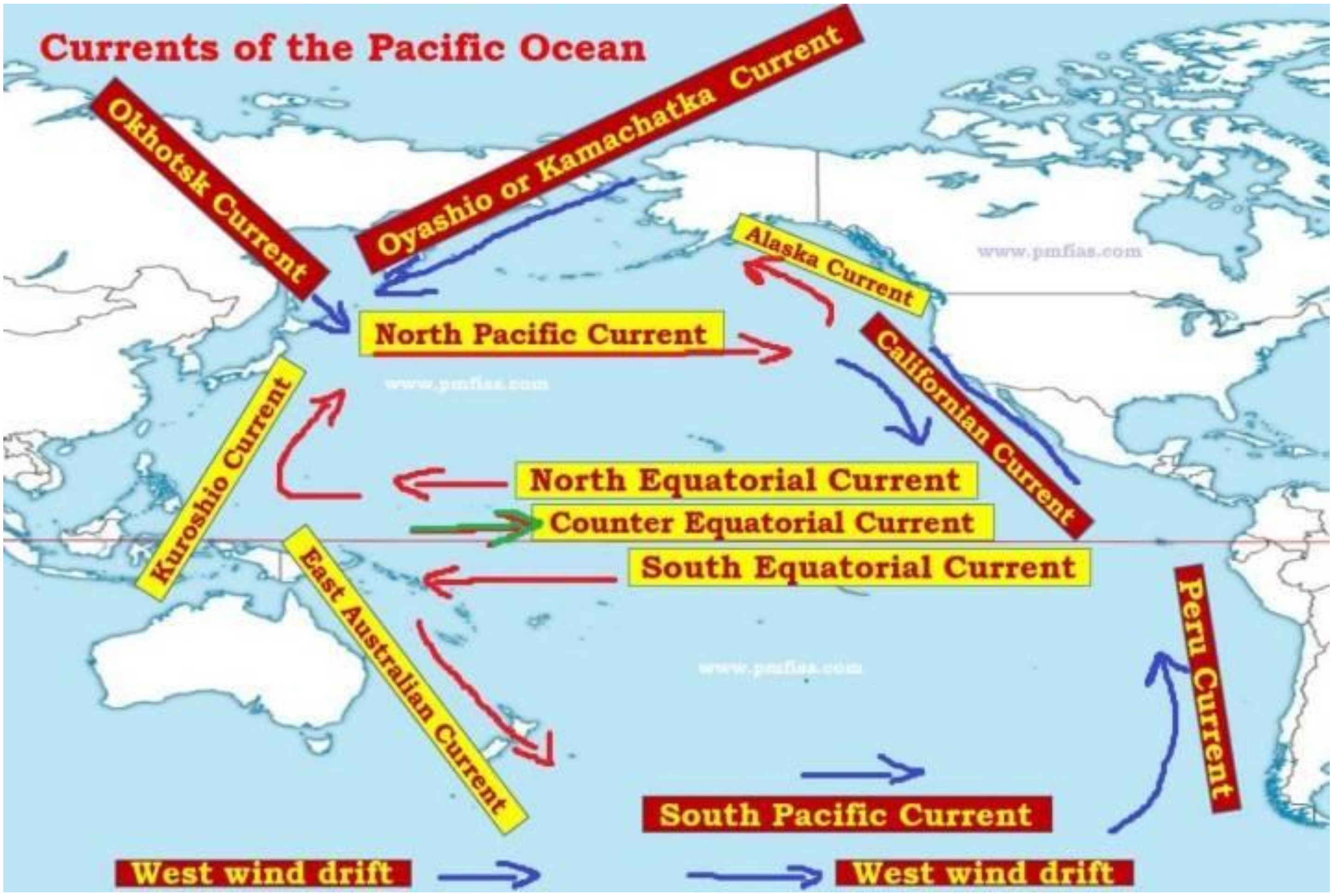
Counter equatorial current

- This raises the level of western pacific (near Indonesia and Australia) ocean by few centimeters. And this creates a

counter-equatorial current which flows between the north equatorial current and the south equatorial current in **west-east** direction.

Three factors aid the formation of Counter-Equatorial current

1. Piling up of water in the western pacific due to trade winds.
2. The presence of doldrums (equatorial low pressure belt) in between the north equatorial current and the south equatorial current. Doldrums are narrow regions with calm (lower) atmospheric conditions. Such conditions aid the backward movement of piled up western pacific waters.



3. Piling of water in the western part of oceans due to rotation of earth (this is a very general point).

Question Prelims 2015

What explains the eastward flow of the equatorial counter-current?

1. The Earth's rotation on its axis
2. Convergence of the two equatorial currents
3. Difference in salinity of water
4. Occurrence of the belt of calm near the equator

This question is a very tricky one.

Opinions can vary.

Should wait for Official Answer Key!

My opinion

Point 1: Very general in nature. So, less important.

Point 2: This is the first step. Without convergence of equatorial currents, there may not be counter equatorial current. But convergence occur due to trade winds

[winds play a superior role in the formation of ocean currents].

Point 3: Salinity greatly influences vertical currents and its influence on horizontal movement is less significant. So, ruled out.

Point 4: This is the main reason behind counter equatorial current (the backward movement of equatorial waters). Doldrums are calm regions facilitating the backward movement of water.

There is a severe clash between Points 2 and 4. My pick is Option D [more probable].

But why? Because the most important factor what influences the direction of ocean currents is wind.

Kuroshio current

- The north equatorial current turns northward off the Philippines to form the **Kuroshio current.** Most of it lies in the **sub-tropical high pressure belt** and its northern part is under the influence of **westerlies.**

Oyashio Current and Okhotsk current

- There are two more cold currents in the northern Pacific, **Oyashio flows** across the east coast of Kamchatka Peninsula to merge with the warmer waters of Kuroshio, and the Okhotsk current flows past **Sakhlain Islands** to merge with the Oyashio current off Hokkaido (Northern Japanese Island).

North-Pacific current

- From the south-east coast of Japan, under the influence of prevailing westerlies, the **Kuroshio current** turns eastwards and moves as the North-Pacific current, reaches the west coast of North America, and bifurcates into two.

Alaska and Californian current

- The northern branch flows anti-clockwise along the coast of British Columbia and Alaska and is known as the **Alaska current**. The water of this current is relatively warm as compared to the surrounding waters in this zone.
- The southern branch of the current moves as a cold current along the west coast of USA and is known as the **Californian current**. The Californian current joins the north equatorial current to complete the circuit.

East Australian current

- Following the pattern in the northern hemisphere, the south equatorial current flows from east to west and turns southwards as the East Australian current. It then meets the South pacific current near Tasmania which flows from west to east.

Peru current or Humboldt Current

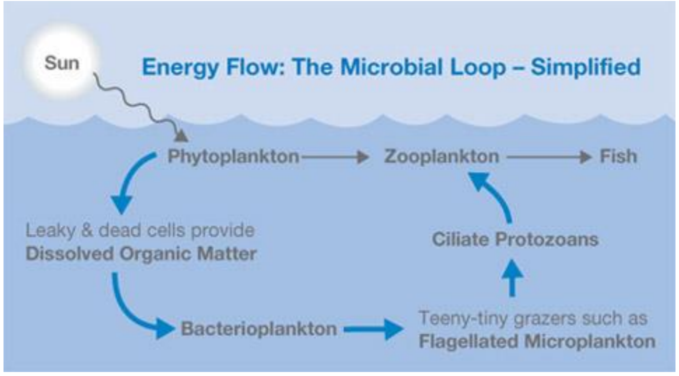
- Reaching the south-western coast of South America, it turns northward as the Peru current. It is a cold current, which finally feeds the south equatorial current, thus completing the great circuit.
- And the zone where Peru Cold current meets the warm equatorial ocean waters is an important fishing zone. Why? Read the topic below.

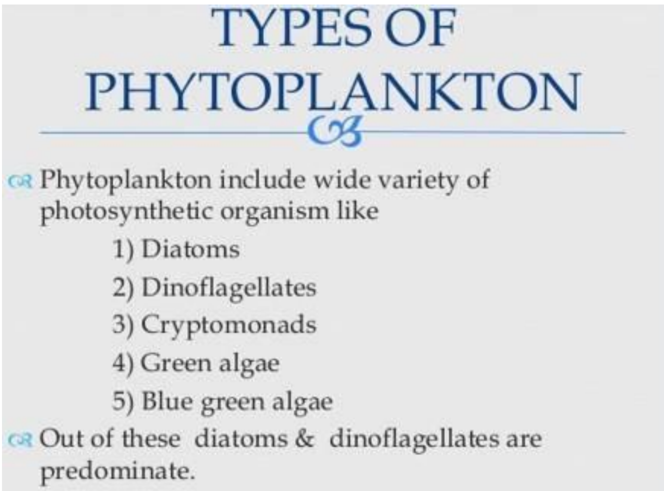
Phytoplankton and Fishing

Mixing zones of Cold and Warm Ocean Currents [Grand Banks] and cold water upwelling zones [Peru coast] are the most productive fishing grounds on earth. Why?

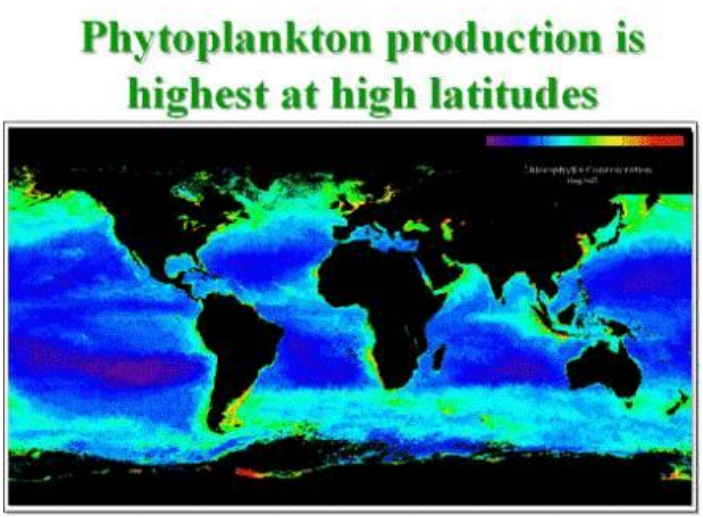
- Phytoplankton are the **primary producers** in the marine food chain and hence they are called the **'grass of the sea'**.
- Phytoplankton are predominantly **microscopic, single celled** organisms.
- Some species of algae are large, multicellular and live on the ocean bottom. However, they are insignificant players in the marine ecosystem compared

to the phytoplankton as they only inhabit a narrow zone around the coast.





Why are cold and warm current mixing zones the good fishing grounds? Why are tropical waters highly *un*productive?



- Algae and other plants are able to **photosynthesize** to produce **organic material** from inorganic nutrients.
- And the organic material forms the building block for all animals higher up in the food chain.
- Almost all biomass in the ocean is derived from the **phytoplankton** and to a lesser extent the **benthic algae** *(found on the bottom of a sea or lake).*
- However, there is a fundamental problem phytoplankton in the open ocean have to face. They **need both sunlight and nutrients** (such as **nitrate** and **phosphate**) to be able to photosynthesize.
- Sunlight is only available in the uppermost layers.
- During photosynthesis, the nutrients are quickly used up by phytoplankton so they are not available for long periods in the upper layers under normal circumstances.

This is indeed the case in tropical waters, and as a result they are very unproductive.

- To escape this problem the seawater needs to be **mixed regularly** to bring the nutrient rich deep waters up to the sunlight zone where the phytoplankton can grow.

This is one of the reasons why cold and warm currents convergence zones [mixing happens – the collision of currents causes mixing] and upwelling zones are very productive.

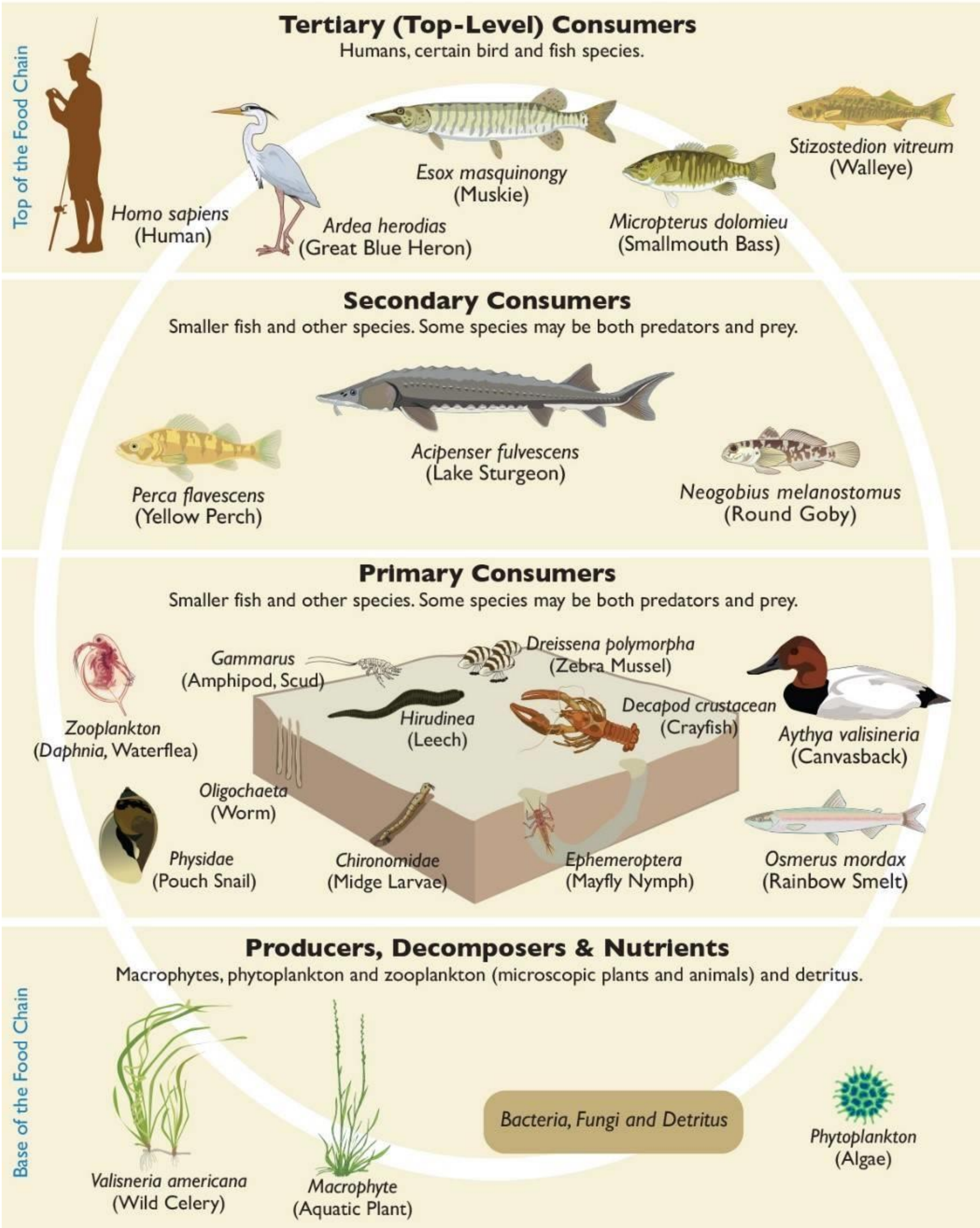
- Furthermore, in surroundings where atmospheric temperatures are often colder than oceanic temperatures, the top layers of the ocean are cooled by the atmosphere.
- This increases the density of the surface waters and causes them to sink and therefore causes mixing [nutrient deficient water sinks and nutrient rich water is upwelled].

Both of these factors play a role in Icelandic waters, resulting in the very productive ocean environment around Iceland.

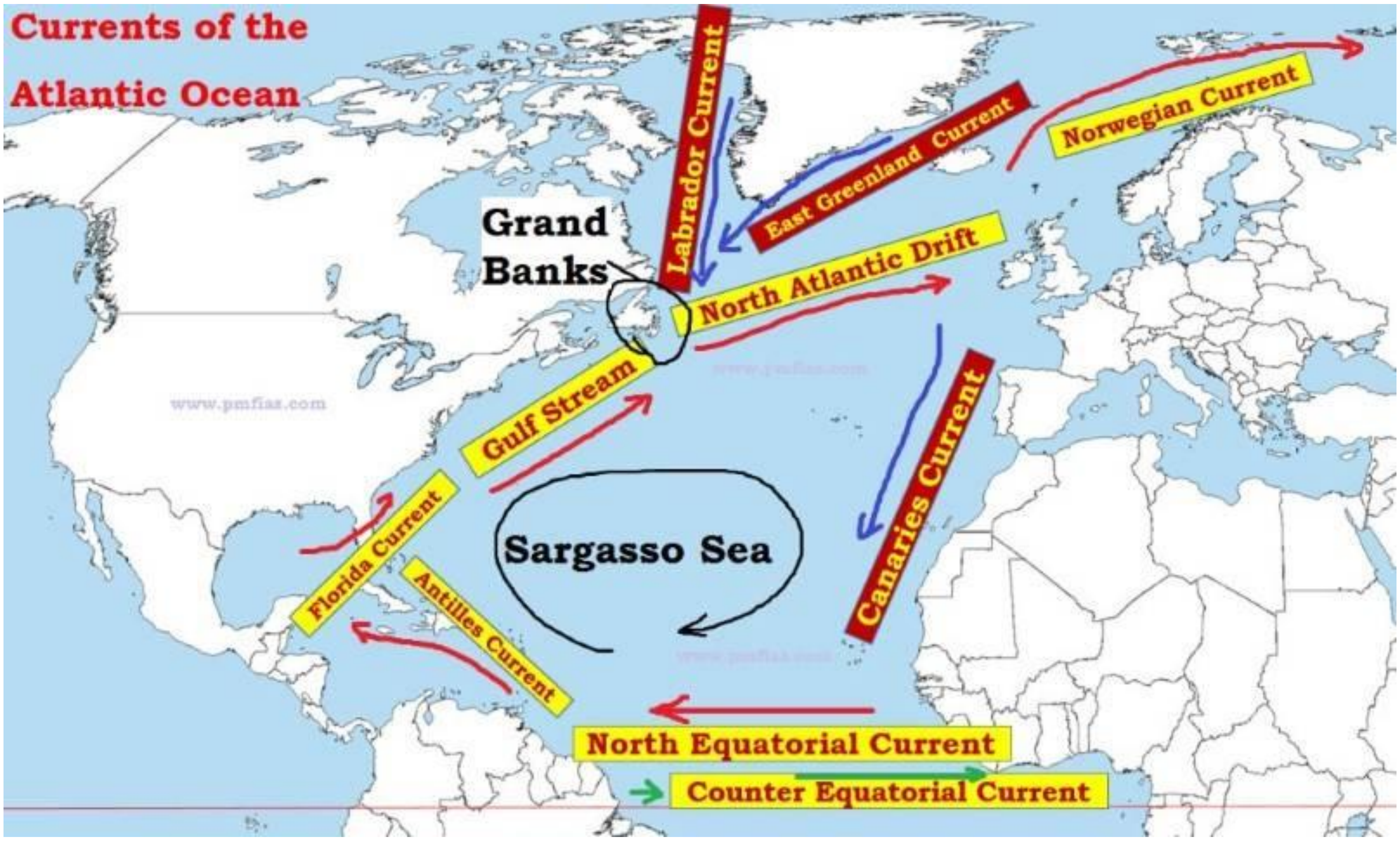
Atlantic Ocean Currents

Aquatic Food Web

The Detroit River and Lake Saint Clair are part of the Great Lakes basin that provides an important food source for the region and the country. Below are sample species in the Great Lakes Aquatic Food Web.



Not to scale. Adapted from *the Life of the Lakes* MICHU 09-400 Michigan Sea Grant, www.miseagrant.umich.edu



Equatorial Atlantic Ocean Currents

- Under the influence of **prevailing trade winds [easterly trade winds]**, the north equatorial current and the south equatorial current start from the eastern Atlantic (west coast of Africa), moving from east to west.
- This raises the level of western Atlantic (north of the Brazil bulge) ocean by few centimeters. And this creates a **counter-equatorial current** which flows between the north equatorial current and the south equatorial current in **west-east** direction.

Antilles current

- The south equatorial current bifurcates into two branches near **Cape de Sao Roque (Brazil).**
- Part of the current enters the Caribbean Sea along with north equatorial current into the Mexican Gulf, while the remainder passes along the eastern side of the West Indies as the **Antilles current.**
- There is a rise in water level in the Mexican Gulf because of large amounts of water brought by the Mississippi river and branches of north and south equatorial currents.

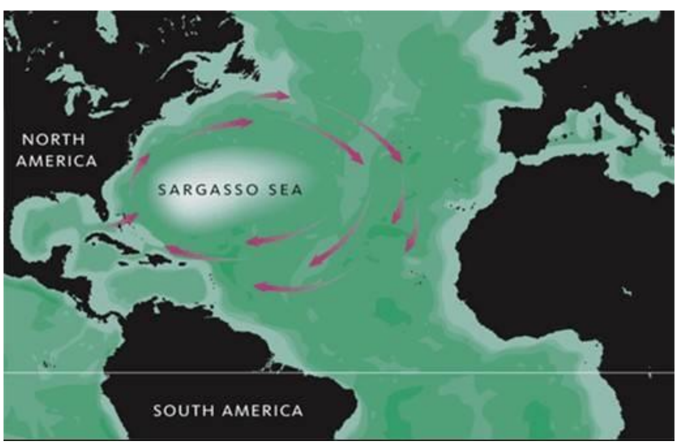
Gulf Stream and North Atlantic Drift

- **Antilles current** creates a current that flows out through the Strait of Florida as **Florida current**, which mixes with Antilles current from the south.
- This combined current moves along the east coast of USA and is known as the Florida current upto the Cape Hatteras and as the Gulf Stream beyond that.
- Near the Grand Banks, the Gulf Stream mixes with cold Labrador and East Greenland currents and flows eastward across the Atlantic as the North Atlantic Drift.
- Here, westerly movement of North Atlantic Drift is due to the influence of **westerlies.**

Norwegian current

- The North Atlantic Current breaks up into two branches on reaching the eastern part of the ocean.
- The main current, continuing as the North Atlantic Drift, reaches the British Isles from where it flows along the coast of Norway as the **Norwegian current** and enters the Arctic Ocean.
- Norwegian current is **very important** as it keeps ocean to the north of Norway partly **free from ice** and also moderates the extremes of climate. It is because of this current, Russia is able to move cargo in summers through **Arctic ocean (Barents Sea).**
- The southerly branch flows between Spain and Azores as the cold Canary current.
- This current finally joins the north equatorial current completing the circuit in the North Atlantic.
- The **Sargasso Sea**, lying within this circuit, is full of large quantities of seaweed and is an important geographical feature.

Sargasso Sea



The Sargasso Sea is a region in the gyre in the middle of the North Atlantic Ocean.
It is the only sea on Earth which has **no coastline.**
It is bounded on the
west by the **Gulf Stream**;
north, by the **North Atlantic Current**;
east, by the **Canary Current**; and
south, by the **North Atlantic Equatorial Current**.
This system of ocean currents forms the **North Atlantic Gyre**.
All the currents deposit the marine plants and refuse they carry into this sea.

Grand Banks-Richest Fishing Grounds on Earth

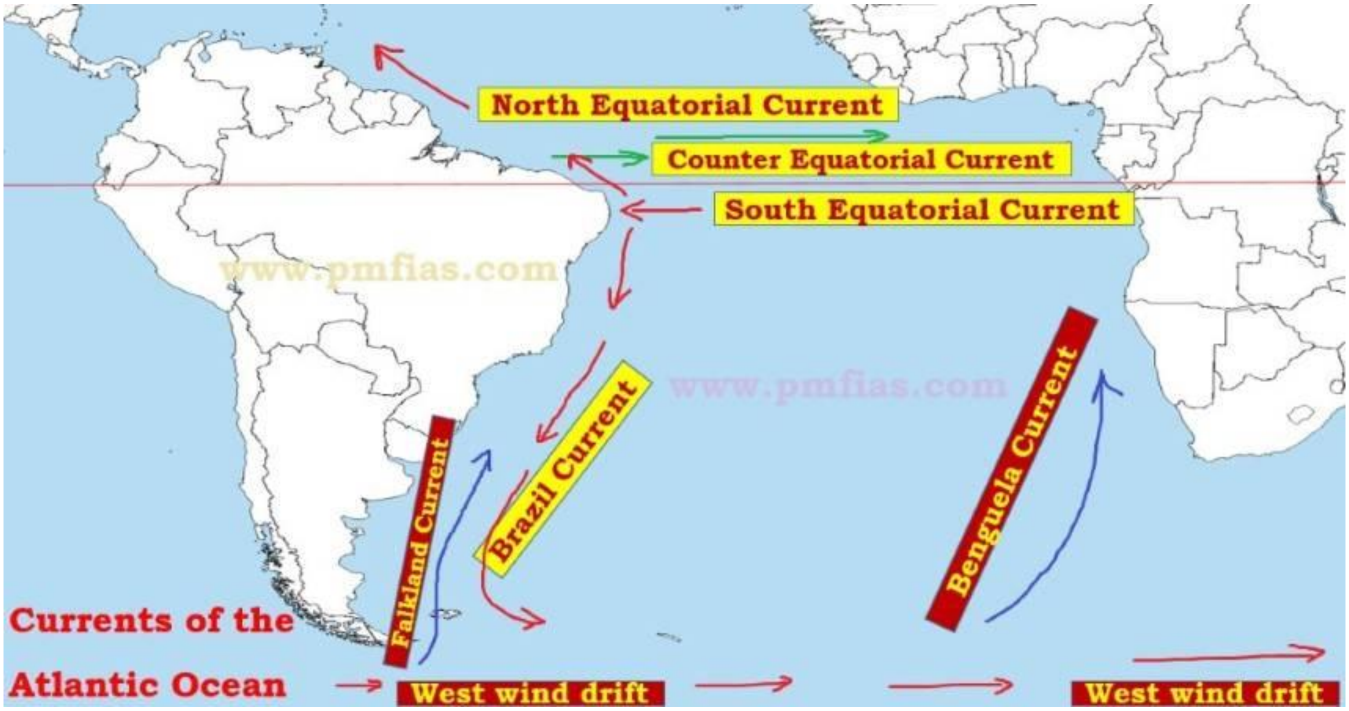
- The two cold currents—East Greenland current and the Labrador current—flow from the Arctic Ocean into the Atlantic Ocean.
- The Labrador current flows along part of the east coast of Canada and meets the warm Gulf Stream.
- The confluence of these two currents, one hot and the other cold, produce the famous **fogs around Newfoundland**.
- As a result of mixing of cold and warm waters, one of the world's most important fishing grounds is created.[Explained in the previous post: Pacific Ocean Currents – Fishing and Phytoplankton]

Brazil current

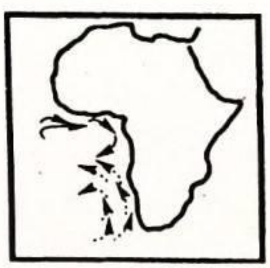
- In the South Atlantic Ocean, the south equatorial current, flowing from east to west, splits into two branches near **Cape de Sao Roque (Brazil).**
- The northern branch joins the north equatorial current (a part of it flows in Anatilles Current and other into Gulf of Mexico), whereas the southern branch turns southward and flows along the South American coast as the warm Brazil current.
- The south flowing Brazil current swings eastward at about latitude 35°S (due to westerlies) to join the **West Wind Drift** flowing from west to east.
- A small branch of West Wind Drift splits and flows between Argentinian coast and **Falkland Islands** and this current is called as **Falkland cold current**.
- It mixes with warm Brazil current at the southern tip of Brazil.

Benguela current

- A branch of the South Atlantic splits at the southern tip of Africa and flows along the west coast of South Africa as the cold Benguela current, which joins the south equatorial current to complete the circuit.



In the given map, which one of the following pairs of ocean currents are shown? *[1999]*



(a) Benguela and Falkland
(b) Canary and Humboldt
(c) Agulhas and Guinea
(d) Benguela and Guinea

In this post: Indian Ocean Currents – Influence of Monsoon Winds on the Indian Ocean Currents.

Previous posts: Pacific Ocean Currents and Atlantic Ocean Currents.

Indian Ocean Currents

- Indian ocean is **half an ocean**, hence the behavior of the North Indian Ocean Currents is different from that of Atlantic Ocean Currents or the Pacific Ocean Currents.
- Also, **monsoon winds** in Northern Indian ocean are peculiar to the region, which directly influence the ocean surface water movement [North Indian Ocean Currents].

Indian Ocean Currents and Monsoons

- The currents in the northern portion of the Indian Ocean change their direction from season to season in response to the **seasonal rhythm of the monsoons**. The effect of winds is comparatively more pronounced in the Indian Ocean.

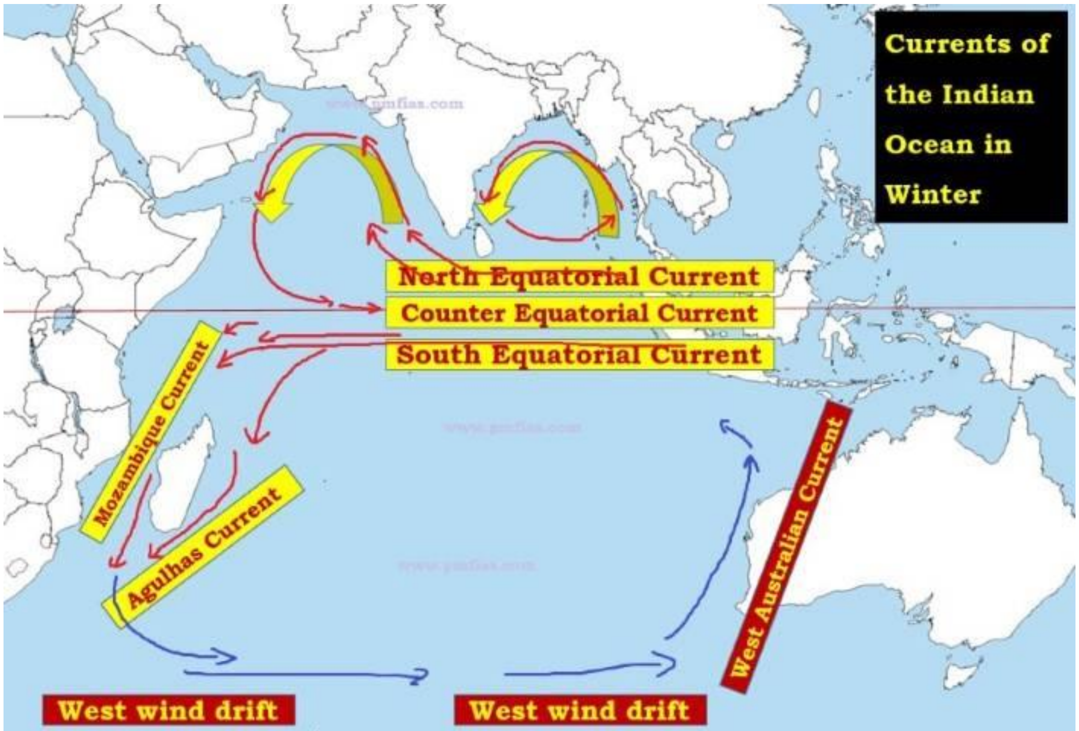
Winter Circulation

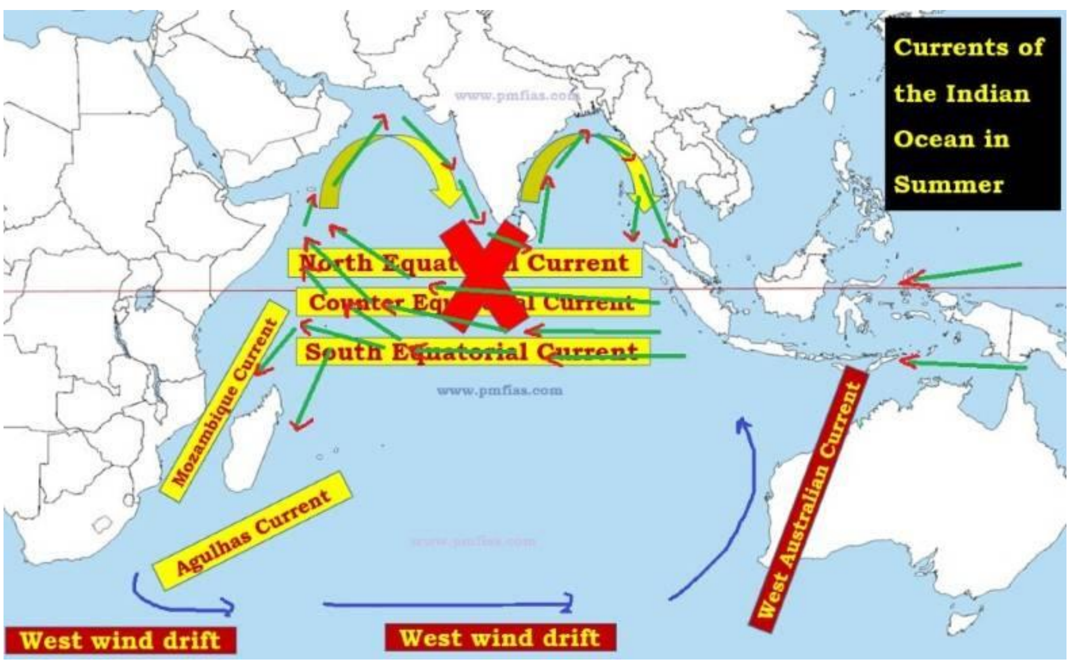
- Under the influence of **prevailing trade winds [easterly trade winds]**, the north equatorial current and the south equatorial current start from the south of Indonesian islands, moving from east to west.
- This raises the level of western Indian (south-east of horn of Africa) ocean by few centimeters. And this creates a **counter-equatorial current** which flows between the north equatorial current and the south equatorial current in **west-east** direction.

- The north-east monsoons drive the water along the coast of Bay of Bengal to circulate in an **anti-clockwise** direction.
- Similarly, the water along the coast of Arabian Sea also circulate in an **anti-clockwise** circulation.

Summer Circulation – North Equatorial Current Counter-Equatorial Current are Absent

- In summer, due to the effects of the strong south-west monsoon and the absence of the north-east trades, a strong current flows from west to east, which completely ***obliterates the north equatorial current***. Hence, there is ***no counter-equatorial current as well.***
- Thus, the circulation of water in the northern part of the ocean is **clockwise** during this season.





Southern Indian Ocean Currents - Agulhas current, Mozambique current, West Australian current

- The general pattern of circulation in southern part of the Indian Ocean is quite similar to that of southern Atlantic and Pacific oceans. It is **less marked by the seasonal changes.**
- The south equatorial current, partly led by the corresponding current of the Pacific Ocean, flows from east to west.
- It splits into two branches, one flowing to the east of Madagascar known as **Agulhas current** and the other between Mozambique and Western Madagascar coast known as **Mozambique current**.
- At the southern tip of Madagascar, these two branches mix and are commonly called as the Agulhas current. It still continues to be a warm current, till it merges with the West Wind Drift.
- The **West Wind Drift**, flowing across the ocean in the higher latitudes from west to east, reaches the southern tip of the west coast, of Australia.
- One of the branches of this cold current turns northwards along the west coast of Australia. This current, known as the **West Australian current**, flows northward to feed the south equatorial current.

In this post: Ocean Salinity – Horizontal Distribution of Ocean Salinity and Vertical Distribution of Ocean Salinity.

Previous Post: Temperature Distribution of Oceans.

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

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

- 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.

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

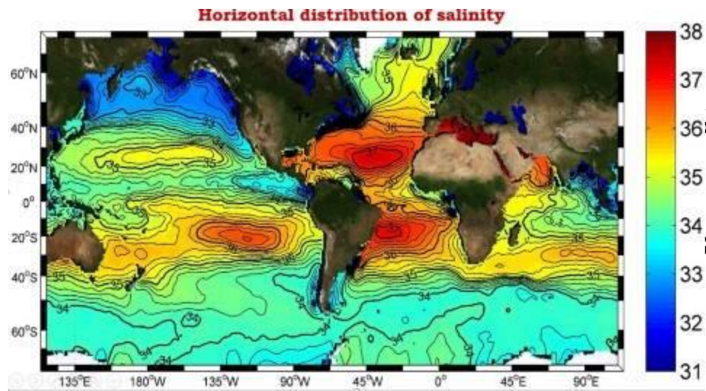
- In the estuaries (enclosed mouth of a river where fresh and saline water get mixed) and the Arctic, the salinity fluctuates from 0 - 35, seasonally (fresh water coming from ice caps).

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.

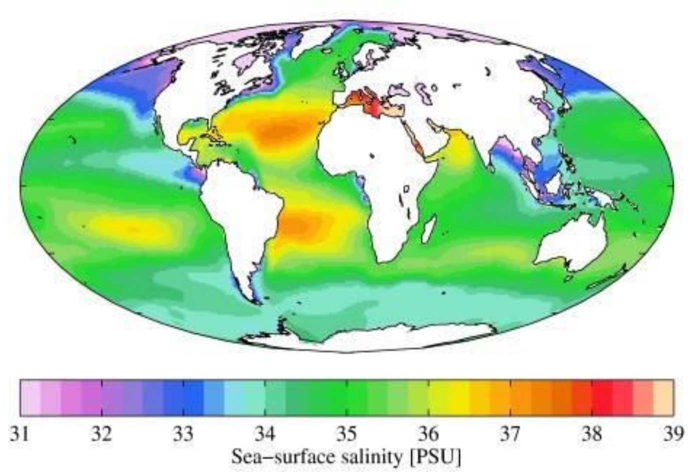


Indian Ocean

- 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.

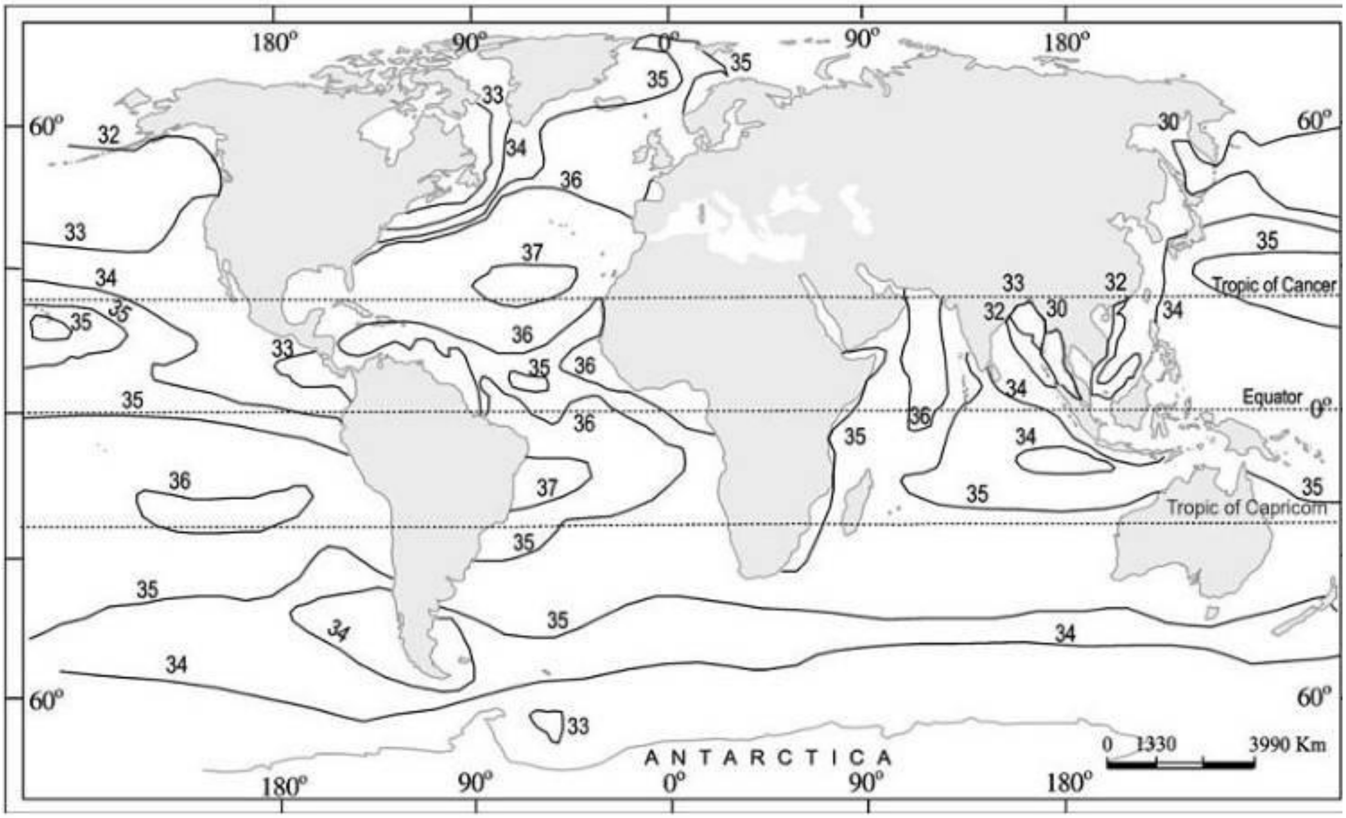


Figure13.5 : Surface salinity of the World's Oceans

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**.

Questions

Multiple choice questions

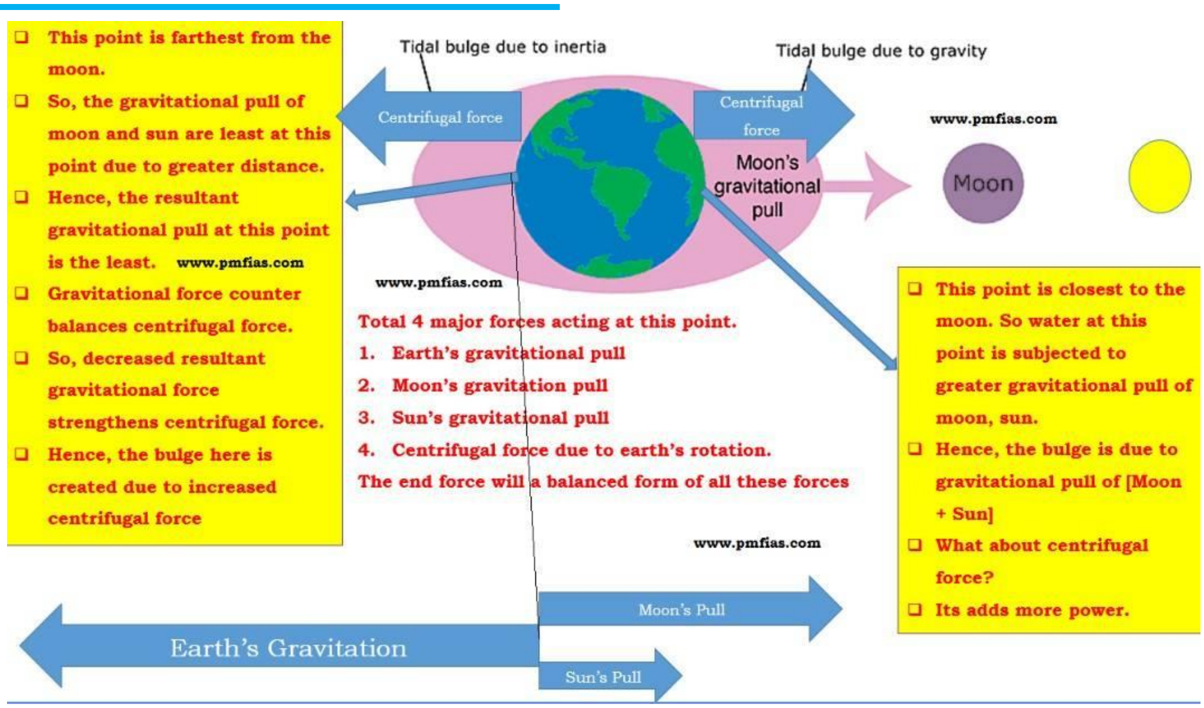
1. Salinity is expressed as the amount of salt in grams dissolved in sea water per (a) 10 gm (c) 100 gm (b) 1,000 gm (d) 10,000 gm
2. Which one of the following is the smallest ocean: (a) Indian Ocean (c) Atlantic Ocean (b) Arctic Ocean (d) Pacific Ocean

In this post: Tides — Tidal Bulge – Why there are two tidal bulges? Why is there a tidal bulge on the other side? Factors Controlling the Nature and Magnitude of Tides; Types of Tides: Semi-diurnal tide, Diurnal tide, Mixed tide, Spring tides, Neap tides, Ebb and Flood; Importance of Tides; Characteristics of Tides; Tidal bore.

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.

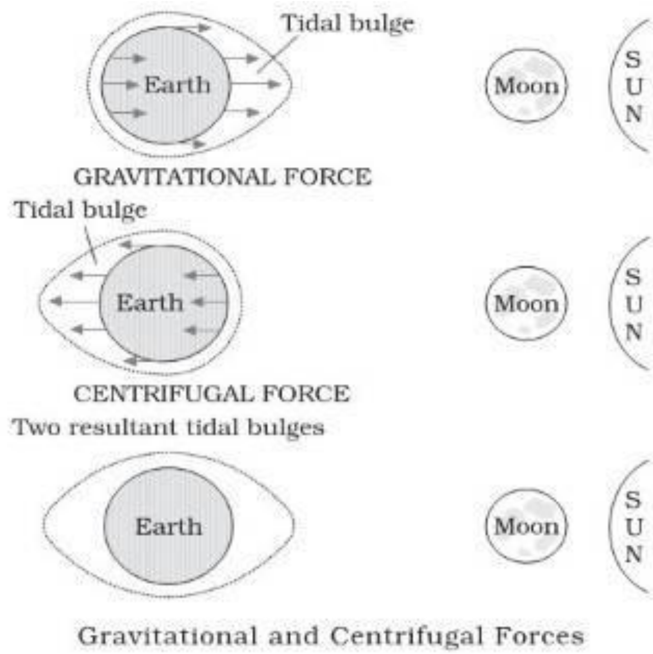


Figure14.2 : Relation between gravitational forces and tides

- 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.

https://www.youtube.com/watch?v=CTQ6ciHENgI

- 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

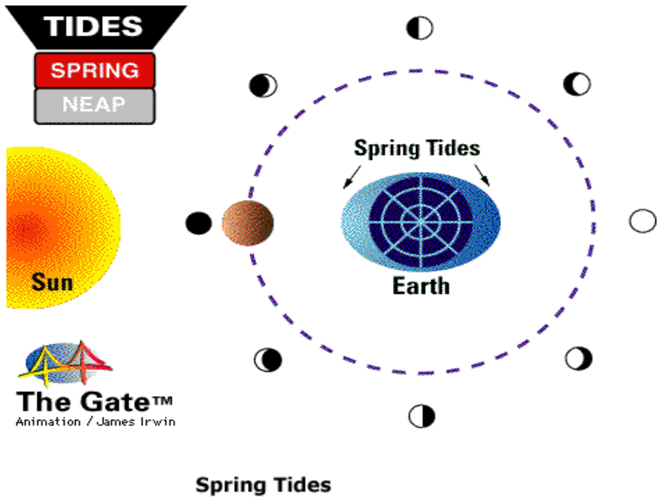
- Normally, there is a **seven day interval** between the spring tides and neap tides.
- At this time the sun and moon are at **right angles** to each other and the forces of the sun and moon tend to counteract one another.
- The Moon's attraction, though more than twice as strong as the sun's, is diminished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

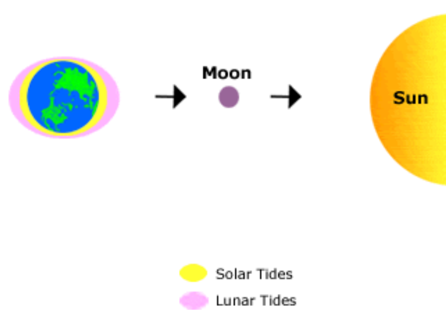
Magnitude of tides based on Perigee and apogee of moon

- 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.





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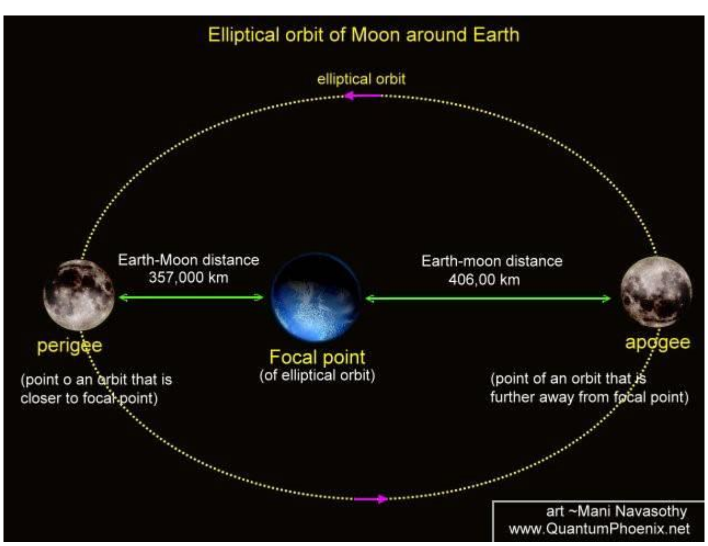
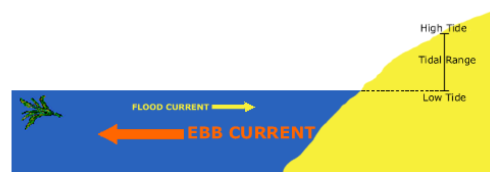


Ebb and Flood

- 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.**



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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.

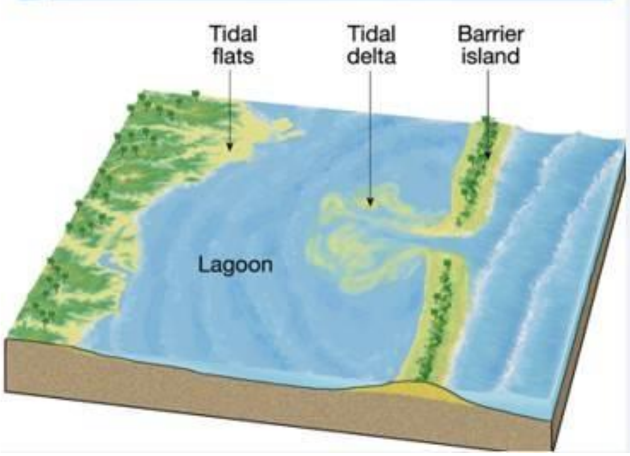
Desilting

- 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.

Tidal bore

- Tides also occur in gulfs. The gulfs with wide fronts and narrow rears experience higher tides.
- The in and out movement of water into a gulf through a channels called a tidal current.
- When a tide enters the narrow and shallow estuary of a river, the front of the tidal wave appears to be vertical owing to the piling up of water of the river against the tidal wave and the friction of the river bed.
- The steep-nosed tide crest looks like a vertical wall of-water rushing upstream and is known as a **tidal bore**.

- The favorable conditions for tidal bore include strength of the incoming tidal wave, slim and depth of the channel and the river flow.
- There are exceptions. The **Amazon River** is the largest river in the world. It empties

into the Atlantic Ocean. The mouth of the Amazon is not narrow, but the river still has a strong tidal bore. A tidal bore develops here because the mouth of the river is shallow and dotted by many low-lying islands and sand bars.

- In India, tidal bores are common in the **Hooghly river**. Most powerful tidal bores occur in ***Qiantang River*** in China.
- The name 'bore' is because of the **sound** the tidal current makes when it travels through narrow channels.
- Bores occur in relatively **few locations** worldwide, usually in areas with a **large tidal range**, typically more than 6 metres (20 ft) between high and low water.
- A tidal bore takes place during the flood tide and never during the ebb tide (Tidal bores almost never occur during neap tides. Neap tides happen during quarter moons, when tides are weakest).

Impact of Tidal Bore

- Tides are stable and can be predicted. Tidal bores are **less predictable** and hence can be **dangerous.**
- The tidal bores adversely affect the shipping and navigation in the estuarine zone.
- Tidal bores of considerable magnitude can capsize boats and ships of considerable size.
- Strong tidal bores disrupt fishing zones in estuaries and gulfs.
- Tidal bores have an adverse impact on the ecology of the river mouth. The tidal-bore affected estuaries are the rich feeding zones and breeding grounds of several forms of wildlife.
- Animals slammed by the leading edge of a tidal wave can be buried in the silty water. For this reason, carnivores and scavengers are common sights behind tidal bores.

Questions

Multiple choice

1. Upward and downward movement of ocean water is known as the:

(a) tide

(b) wave

(c) current

(d) none of the above

2. Spring tides are caused:

(a) As result of the moon and the sun pulling the earth gravitationally in the same direction.

(b) As result of the moon and the sun pulling the earth gravitationally in the opposite direction.

(c) Indention in the coast line.

(d) None of the above.

3. The distance between the earth and the moon is minimum when the moon is in:

(a) Aphelion

(b) Perihelion

(c) Perigee

(d) Apogee

4. The earth reaches its perihelion in:

(a) October

(b) July

(c) September

(d) January

150 Words

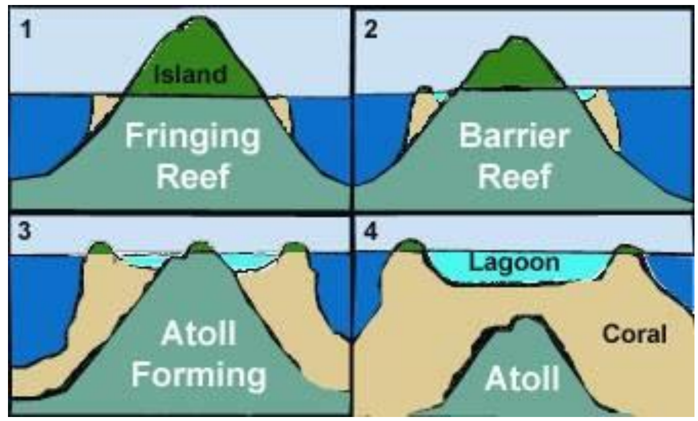
- What are tides? How are tides caused? How are tides related to navigation?

In this post: Coral Reef — Coral Reef Relief Features – Fringing Reefs (Shore Reefs), Barrier Reefs and Atolls. Development Of Major Coral Reef Types [Formation Of Lakshadweep Islands]

Next Post: Coral Bleaching — Ideal conditions for coral growth, Zooxanthellae, Cause for Coral Bleaching, Distribution of Coral Reefs etc..

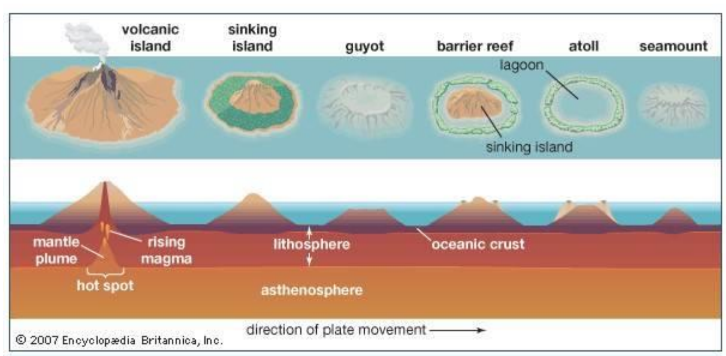
Coral Reefs

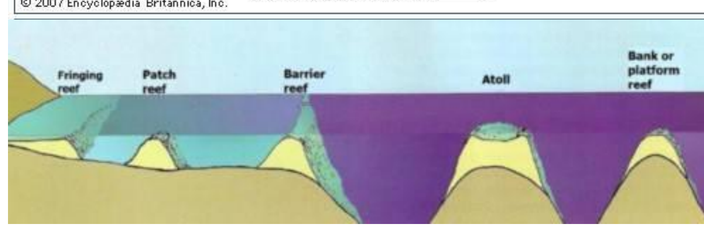
- Coral reefs are built by and made up of thousands of tiny animals—**coral "polyps"**—that are related to **anemones and jellyfish.**
- Polyps are **shallow water organisms** which have a soft body covered by a **calcareous skeleton**. The polyps extract calcium salts from sea water to form these hard skeletons.
- The polyps live in colonies fastened to the rocky sea floor.
- The tubular skeletons grow upwards and outwards as a cemented calcareous rocky mass, collectively called **corals.**
- When the coral polyps die, they shed their skeleton [coral] on which new polyps grow.
- The cycle is repeated for over millions of years leading to accumulation of layers of corals [shallow rock created by these depositions is called **reef**].
- These layers at different stages give rise to various marine landforms. One such important landform is called **coral reef.**
- Coral reefs over a period of time transform or evolve into **coral islands (Lakshadweep).**
- The corals occur in different forms and colours, depending upon the **nature of salts** or constituents they are made of.
- Small marine plants **(algae)** also deposit calcium carbonate contributing to coral growth.



Coral Reef Relief Features

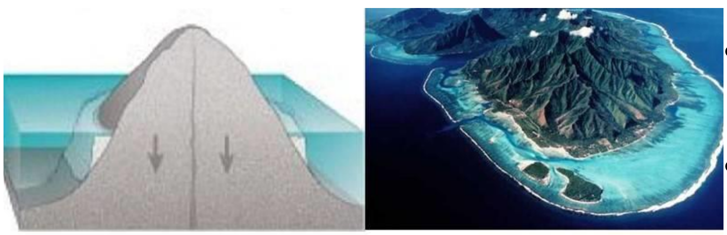
- **Fringing reef, barrier reef** and **atoll (coral islands are formed on atolls)** are the most important relief features.





Fringing Reefs (Shore Reefs)

- Fringing reefs are reefs that **grow directly from a shore**. They are located very **close** to land, and often form a **shallow lagoon** between the beach and the main body of the reef.
- A fringing reef runs as a narrow belt [1-2 km wide]. This type of reef grows from the deep sea bottom with the seaward side sloping steeply into the deep sea. Coral polyps do not extend outwards because of **sudden and large increase in depth**.
- The fringing reef is by far the ***most common*** of the three major types of coral reefs, with numerous examples in all major regions of coral reef development.
- Fringing reefs can be seen at the New Hebrides Society islands off Australia and off the southern coast of Florida.

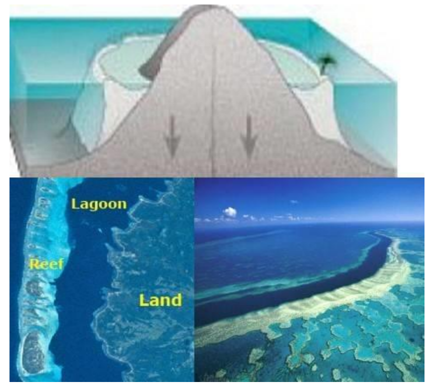


WHAT IS A "LAGOON"?

A lagoon - as used in the context of coral reef typology - refers to a comparatively wide band of water that lies between the shore and the main area of reef development, and contains at least some deep portions.

Barrier Reefs

- Barrier reefs are **extensive linear reef** complexes that **parallel a shore**, and are separated from it by **lagoon**.
- This is the **largest (in size, not distribution)** of the three reefs, runs for hundreds of kilometres and is several kilometres wide. It extends as a broken, irregular ring around the coast or an island, running almost parallel to it.
- Barrier reefs are **far less common** than fringing reefs or atolls, although examples can be found in the tropical Atlantic as well as the Pacific.
- The **1200-mile long Great Barrier Reef** off the NE coast of Australia is the world's largest example of this reef type.
- The GBR is not actually a single reef as the name implies, but rather a very large complex consisting of **many reefs**.



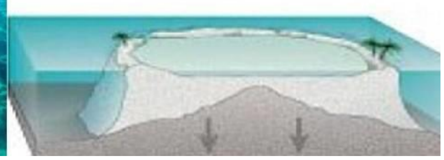
Atolls

- An atoll is a roughly circular (annular) oceanic reef system surrounding a large (and **often deep) central lagoon**.
- The lagoon has a depth 80-150 metres and may be joined with sea water through a number of channels cutting across the reef.
- Atolls are located at **great distances** from deep see platforms, where the submarine features may help in formation of atolls, such as a **submerged island or a volcanic cone** which may reach a level suitable for coral growth.
- An atoll may have any one of the following three forms-

1. **true atoll—a circular reef enclosing a lagoon with no island;**
2. **an atoll surrounding a lagoon with an island;**
3. **a coral island or an atoll island which is, in fact, an atoll reef, built by the process of erosion and deposition of waves with island crowns formed on them.**

- Atolls are **far more common in the Pacific** than any other ocean. The **Fiji atoll** and the Funafuti atoll in the Ellice/Island are well known examples of atolls. A large 'number of atolls also occur in the **Lakshadweep Islands.**

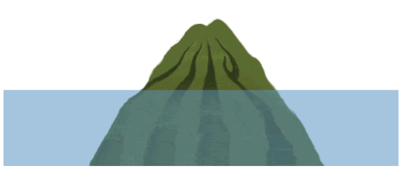
- In the South Pacific, most atolls occur in mid-ocean. Examples of this reef type are common in **French Polynesia**, the **Caroline and Marshall Islands**, **Micronesia**, and the **Cook Islands.**
- The Indian Ocean also contains numerous atoll formations. Examples are found in the **Maldives** and **Chagos island groups,** the **Seychelles,** and in the **Cocos Island group**.



Development Of Major Coral Reef Types

Formation Of Lakshadweep Islands [You must include the concept of Hotspot]

- The basic coral reef classification scheme described above was first proposed by **Charles Darwin**, and is still widely used today.
- Darwin theorized that fringing reefs began to grow **near the shorelines** of new islands as ecological conditions became ideal for hard coral growth.
- Then, as the island began to gradually **subside** into the sea, the coral was able to keep pace in terms of growth and remained in place at the sea surface, but farther from shore; it was now a barrier reef.
- Eventually, the island disappeared below the sea surface, leaving only the ring of coral encircling the central lagoon; an atoll had formed.



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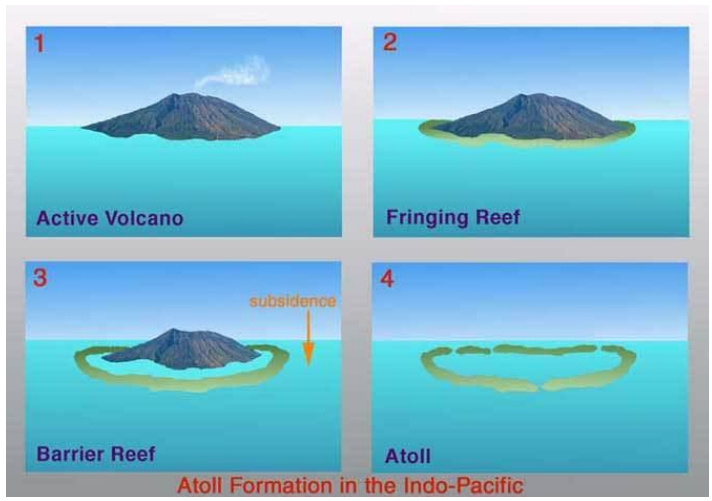
1. Step 1: A fringing reef forms first, and starts growing in the shallow waters close to a tropical island.
2. Step 2: Over time, the island subsides and the reef grows outwards, and the distance between the land and the reef increases. The **fringing reef develops into a barrier reef**.
3. Step 3: If the island completely subsides, all that is left is the reef. The reef retains the approximate shape of the island it grew around, forming a ring enclosing a lagoon.



In this post: Coral Bleaching — Ideal conditions for coral growth, Zooxanthellae, Cause for Coral Bleaching, Distribution of Coral Reefs etc..

Previous Post: Coral Reef — Coral Reef Relief Features – Fringing Reefs (Shore Reefs), Barrier Reefs and Atolls, Development Of Major Coral Reef Types.

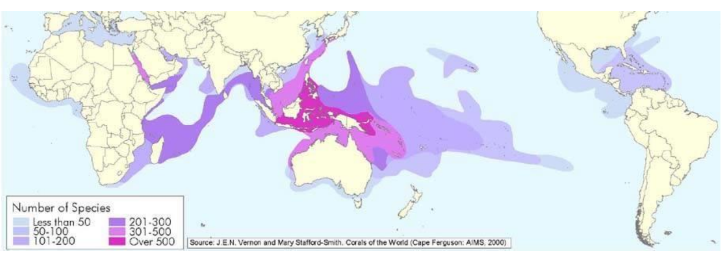
Ideal Conditions for Coral Growth

- **Stable climatic conditions:** Corals are highly susceptible to quick changes. They grow in regions where climate is significantly stable for a long period of time.
- **Perpetually warm waters:** Corals thrive in **tropical waters** [30°N and 30°S latitudes, The temperature of water is around 20°C] where diurnal and annual temperature ranges are very narrow.

[Explain why coral reefs are absent on west coast of tropical continents? Because of Cold Ocean Currents – corals like warm waters and hate cold waters]

- **Shallow water:** Coral require fairly good amount of **sunlight** to survive. The ideal depths for coral growth are 45 m to 55 m below sea surface, where there is abundant sunlight available.
- **Clear salt water:** Clear salt water is suitable for coral growth, while both fresh water and highly saline water are harmful.
- **Abundant Plankton:** Adequate supply of oxygen and microscopic marine food, called **plankton [phytoplankton]**, is essential for growth. As the plankton is more abundant on the **seaward side**, corals grow rapidly on the seaward side.
- **Little or no pollution:** Corals are highly fragile and are vulnerable to climate change and pollution and even a minute increase in marine pollution can be catastrophic.

Distribution of Coral Reefs



Corals and Zooxanthellae

- Many invertebrates, vertebrates, and plants live in close association with corals, with **tight resource coupling and recycling**, allowing coral reefs to have extremely high productivity and biodiversity, such that they are referred to as **'the Tropical Rainforests of the Oceans'.**
- Scleractinian corals build skeletons of calcium carbonate **sequestered** from the water.
- Scleractinian corals come under **Phylum Cnidaria**, and they receive their nutrient and energy resources in two ways.

1. They use the traditional cnidarian strategy of capturing tiny planktonic organisms with their tentacles (All about Phylum Cnidaria is given in NCERT).
2. Having a symbiotic relationship with a **single cell algae** known as **ZOOXANTHELLAE.**

- Zooxanthellae are **autorophic [prepare their own food] microalgaes** belonging to various taxa in the **Phylum Dinoflagellata.**

Coral == Phylum Cnidaria.

Zooxanthellae == Phylum Dinoflagellata.

Symbiotic Relationship Between Corals And ZOOXANTHELLAE

- Zooxanthellae live symbiotically within the coral polyp tissues and **assist the coral in nutrient production through its photosynthetic activities**.
- These activities provide the coral with **fixed carbon compounds for energy, enhance calcification, and mediate elemental nutrient flux.**
- The host coral polyp in return provides its zooxanthellae with a **protected environment** to live within, and a **steady supply of carbon dioxide** for its photosynthetic processes.
- The symbiotic relationship allows the slow growing corals to compete with the faster growing multicellular algaes. The corals can feed by day through **photosynthesis** and by night through **predation**.

The tissues of corals themselves are actually not the beautiful colors of the coral reef, but are instead clear. The corals receive their coloration from the ZOOXANTHELLAE living within their tissues.

Coral Bleaching or Coral Reef Bleaching

- Disturbances affecting coral reefs include anthropogenic and natural events.
- Recent accelerated coral reef decline is related mostly to anthropogenic impacts **(overexploitation, overfishing, increased sedimentation and nutrient overloading).**
- Natural disturbances which cause damage to coral reefs include **violent storms, flooding, high and low temperature extremes, El Nino Southern Oscillation (ENSO) events, sub aerial exposures, predatory outbreaks and epizootics.**
- Coral reef bleaching is a common **stress response** of corals to many of the various disturbances mentioned above.
- Bleaching occurs when

1. **the densities of zooxanthellae decline and/or**
2. **the concentration of photosynthetic pigments within the zooxanthellae fall. [it is no more useful for the coral and the coral will bleach it]**

- When corals bleach they commonly **lose 60-90% of their zooxanthellae** and each zooxanthellae may **lose 50-80% of its photosynthetic pigments**.
- If the **stress-causing** bleaching is not too severe and if it decreases in time, the affected corals usually regain their symbiotic algae within several weeks or a few months.
- If zooxanthellae loss is prolonged, i.e. if the stress continues and depleted zooxanthellae populations do not recover, the coral host eventually dies .

Ecological Causes of Coral Bleaching

Temperature

- Coral species live within a relatively narrow temperature margin, and **anomalously low and high sea**

temperatures [corals are absent on the west coast of tropical temperate continents because of the cold currents] can induce coral bleaching.

- Bleaching events occur during sudden temperature drops accompanying intense upwelling episodes [El-Nino], seasonal cold-air outbreaks.
- Most reefs recovered, with low levels of coral deaths, but damage has been severe at places.
- This is an instance of coral reefs' susceptibility to increased water temperatures combined with **OCEAN ACIDIFICATION.**
- While the rising temperatures have increased the frequency and intensity of bleaching, acidification has **reduced corals calcifying ability.**
- Small temperature increase over many weeks or large increase (3-4 °C) over a few days will result in **coral dysfunction.**
- Coral bleaching has occurred mostly during the summer seasons or near the end of a protracted warming period.
- They are reported to have taken place during times of **low wind velocity, clear skies, calm seas and low turbidity.** The conditions favor localised heating and high ultraviolet (UV) radiation.
- UV radiation readily penetrates clear sea waters. The corals actually contain UV-absorbing compounds which can block potentially damaging UV radiation. But rising temperatures mean reduction in the concentration of these UV absorbing compounds in corals.

Sub aerial Exposure

- Sudden exposure of reef flat corals to the atmosphere during events such as extreme low tides, ENSO-related sea level drops or tectonic uplift can potentially induce bleaching.
- The consequent exposure to high or low temperatures, increased solar radiation, desiccation, and sea water dilution by heavy rains could all play a role in zooxanthellae loss, but could also very well lead to coral death.

Fresh Water Dilution

- Rapid dilution of reef waters from storm-generated precipitation and runoff has been demonstrated to cause coral reef bleaching.
- Generally, such bleaching events are rare and confined to relatively small, near shore areas.

Inorganic Nutrients

- Rather than causing coral reef bleaching, an increase in ambient elemental nutrient concentrations (e.g. **ammonia and nitrate**) actually increases zooxanthellae densities 2-3 times.
- Although **eutrophication** is not directly involved in zooxanthellae loss, it could cause secondary adverse effects such as **lowering of coral resistance and greater susceptibility to diseases.**

Xenobiotics

- When corals are exposed to high concentrations of chemical contaminants like copper, herbicides and oil, coral bleaching happens.

Epizootics

- **Pathogen** induced bleaching is different from other sorts of bleaching.
- Most coral diseases cause patchy or whole colony death and sloughing of soft tissues, resulting in a white skeleton (not to be confused with bleached corals).

Spatial and temporal range of coral reef bleaching

- Nearly all of the world's major coral reef regions (Caribbean/ western Atlantic, eastern Pacific, central and western Pacific, Indian Ocean, Arabian Gulf, Red Sea) experienced some degree of coral bleaching and mortality during the 1980s.

- Prior to the 1980s, most mass coral moralities were related to non-thermal disturbances such as storms, aerial exposures during extreme low tides, and Acanthaster outbreaks. Coral bleaching accompanied some of the mortality events prior to the 1980s during periods of elevated sea water temperature, but these disturbances were geographically isolated and restricted to particular reefs zones. In contrast, many of the coral bleaching events observed in the 1980s occurred over large geographic regions and at all depths.

Bleaching may also be Beneficial

- Recent research has revealed that corals that are consistently exposed to low levels of stress may develop some kind of resistance to bleaching.

Ocean Deposits

- There are unconsolidated sediments, deposited on the ocean floor. These are ocean deposits. They vary from location to location. The study of ocean deposits is important in understanding the rocks exposed on the earth's surface which were once laid under sea.
- **Two Types** The ocean deposits can broadly be divided into two types—the **terrigenous deposits** and the **pelagic deposits**. The terrigenous deposits are those which are found on the continental shelves and slopes and mainly consist of the rock material derived because of wear and tear. The pelagic deposits are those which are found over deep sea plains and the deeps. These deposits mainly consist of organic remains of plants and animals. But this distinction between the two types of deposits is not absolute. For instance, the terrigenous deposits may not always consist of the fragmented rock material and may be carried deep into the sea. Also, the pelagic deposits may not always consist of the plant and animal remains and may be extended far upto the continental slope.

Terrigenous Deposits

- Terrigenous deposits are derived from the wear and tear of land and volcanic and organic products. The greater part of the deposits on the continental shelf and slopes is derived from rock material let loose by disintegration and decomposition by the agents of weathering and carried to sea by the agents of erosion, such as running water, wind, etc. The process and extent of disintegration depends on. the nature of rock material, climate and time taken. The larger particles of the terrigenous deposits are found near the shore and the finer ones carried deeper. The extent to which they are carried - outwards depends on the size of rock material and the strength of sea waves and currents (Fig. 3.13).
- On the basis of size of particles, the terrigenous deposits may be categorised into three classes—mud, sand and gravel. Mud refers to the finest particles which comprise the minute particles of rock forming minerals, principally quartz. Sand refers to the coarser particles, while gravel has even bigger particles.
- **Volcanic Products** In volcanic regions the deposits of continental shelf and slope consist chiefly of products of volcanism, which are subject to chemical and mechanical weathering and are carried to the ocean by actions of running water and wind. The volcanic deposits differ from the ordinary terrigenous deposits in one respect—they are made of pyroclastic yolcanic products and lava, rather than quartz.
- **Organic Products** Such deposits consist of shells and skeletons of various plants and animals that live and grow on the sea floor and are changed into mud and sand by chemical and mechanical processes. They differ from the ordinary terrigenous deposits in the sense that they consist of calcium carbonate only.

Pelagic Deposits

- Pelagic deposits are the most conspicuous of all deposits—covering about 75% of the total sea floor. This is because, except for fine volcanic ash, little terrigenous material is carried into the deeps. The pelagic deposits consist of both organic and inorganic material.
- **Organic Material** This is in the form of a kind of liquid mud, called **ooze**, which contains shells and skeletons of various marine organisms. The ooze is said to be calcareous when the shell is made of calcium carbonate.

The calcareous ooze may be either pteropod ooze or globogerina ooze. Most parts of the Indian and Atlantic Oceans have calcareous ooze as deposits (Fig. 3.13). When the shell is made of silica, the ooze is said to be siliceous ooze, which can be either the diatom type or the radiolarian type of ooze. The southern fringes of the Indian and the Atlantic Oceans have the siliceous type of ooze.

- **Inorganic Material** This is in the form of red clay, which is apparently of a volcanic origin. The chief constituents of red clay are **silicon** and **aluminium dioxide**, while other constituents include iron, manganese, phosphorus and radium. The **red clay** is the most widely spread pelagic deposit and covers 38% of the sea floor. The red clay covers more than half of the Pacific floor (Fig. 3.13).

Mineral Resources

- The mineral resources, derived from the sea, include both metallic and non-metallic minerals which are present, either in the dissolved form or as suspensions. The dissolved salts that are extracted profitably at present include common salt (sodium chloride) and the salts of magnesium and bromine. The real source of minerals available in the sea is land. Precipitation carries vast amounts of minerals from land on its return journey. Sea mining, however, is upto twenty times more expensive than land mining.
- ***The surface deposits of minerals on the continental shelf and slopes are found mixed with sand. Sands are mined to extract calcium carbonate along the Bahamas coast which is rich in this salt. Coral sands are mined in Hawaii and Fiji. The beach sands of western India, coastal Brazil, Australia, New Zealand, Sri Lanka and the USA have zircon, monazite and rutile. While Kerala's placer deposits contain 90 per cent of the world's monazite reserves, the eastern and western coasts of Australia account for about 30 per cent of rutile. Sulphur reserves are known to exist in the Gulf of Mexico and the Mediterranean Sea. Phosphorite can be mined to produce phosphates; it is found in shallow waters in muds and sands as well as in the form of nodules on the continental Shelf and slopes. Large deposits are known to occur off the coasts of California, Florida, Mexico, Peru, Japan, northwestern and southern Africa, and Australia. Magnetite occurs in areas with deposits of volcanic rock materials. Such areas are found along the east coast of Asia in Japan and the western coast of North America. The tin ore, cassiterite, is a residue of granite weathering and occurs in a belt from northern Thailand-western Malaysia to Indonesia. It has been mined for years and provides more than 1 per cent of the world's produce of tin. Gold placers occur along the coast of Alaska on the East Pacific shelf. Platinum mixed with sand occurs in Australia, South Africa and US. Diamonds are found in sediments washed down the rivers in some areas of Africa and Australia.***
- ***Oil (petroleum) and natural gas are the most well exploited (so far) of all the mineral resources derived from the sea. They constitute upto 90 per cent of the value of minerals derived from sea. The oil and natural gas resources are subsurface deposits found mainly on continental shelves, slopes and in small ocean basins. One structure that acts as a trap for oil and natural gas is the salt dome. (These domes are often also rich in sulphur.) The main prospects for petroleum deposits are youthful margins where some basins contain thick accumulations of sediments. Oil may also occur at convergence zones and near transition faults. According to some scientists, upto 20 per cent of the oil and gas resources are in the offshore areas. The oil crisis has increased the importance of offshore exploration and production. Major offshore oil fields are in the Persian Gulf, Gulf of Mexico, the North Sea, and off the north coast of Australia, the southern coast of US, and the coasts in Arctic Ocean. The western coast of India has shown promising reserves. Relatively unexplored reserves are known to exist around Sumatra, Borneo, East Africa, Northwest Africa, and Australia.***
- ***Besides oil, submerged coal deposits are to be found in Japan, UK, Africa and the coast of Maharashtra in India.***
- ***The deep sea has two main types of mineral deposits of economic importance: manganese nodules and metalliferous sediments.***

- ***Manganese nodules (containing mainly cobalt, copper, nickel and manganese) are abundant in areas of low sedimentation rates, such as abyssal plains. Estimates are that as much as 25 per cent of the sea floor is covered by nodules and that over 1.5 trillion tons are in the Pacific alone, especially in the siliceous ooze area. The nodules of Atlantic and Indian Oceans are generally characterised by having copper, nickel and cobalt below those generally considered economic. Manganese nodules in Indian Ocean cover a large area, over 10 million sq. km. Distribution maps indicate that large areas in the basins east of the Central Indian Ridge contains nodules with a high percentage of manganese, nickel and copper and these appear to be more promising basins. According to recent surveys the Central Indian Ocean Basin's nodules are associated with palae clays.***
- ***Considerable interest has been sparked by the discovery of polymetallic sulphides. They occur along the mid-ocean rift valleys, and those found near the Galapagos rift system contain 48 per cent sulphur, 43 per cent iron, 11 per cent copper and smaller quantities of zinc, tin, molybdenum, lead and silver. The sulphides apparently result from submarine hydrothermal precipitation along the northern boundary fault of the rift valley at depths exceeding 2,000 m. India has located few scattered deposits of polymetallic sulphides in the central Indian Ocean.***

Energy Resources

- Energy from the ocean is derived in three ways.
- **Energy from Tides** The tides, during rise and fall, release a lot of energy by striking against the shore. This piston action can be used to operate a turbine and produce electricity. The USA, the CIS, Japan and France are producing power from ticks.
- **Energy from Temperature**
- **Difference in Surface and Sub-Surface Water** In tropical seas, the surface temperature is about 25 °C to 30 °C, while the sub-surface temperature is 5 °C. This vertical difference of 25 °C is enough to generate electricity, but it is an expensive option. The mechanism involved is called OTEC. Belgium and Cuba are producing power in this way.. In India, a plant of 100 MW is expected to come up at Kulsekaripattinam (Tamil Nadu coast).
- Geothermal Energy This means tapping heat from fracture zones and active volcanoes under sea. [These resources are discussed in detail in the chapter Economic Geography.)

Fresh Water

- The sea water could be the source of an invaluable item—fresh water. Severgl desalination technologies are in operation, but as yet they are not being used on a large scale, as they are costly. Electrodialysis employs iron-selective membranes for the desalination of brackish water. The energy cost of the process is directly proportional to the salinity, and more economical for salinities below 5,000 ppm. Flash distillation is another method of desalinating sea water. In this method, heated saline water is allowed to flow through a series of chambers which are maintained at different pressures below atmospheric, and progressively decrease towards the end of the series. In each section of the chamber, vapour is released and then condensed over a bundle of tubes cooled by circulating sea-water inside them. Distillate of fresh water produced at each stage is gathered. The technique is in use in Saudi Arabia, Kuwait, Island, Pakistan, Chile, and India. Reverse osmosis is the most widely used method. Suitable osmotic membranes are used which reject salts and allow water to pass through when sea water is put under high pressure.

Sea Level Change

- By changes in sea level, we mean the fluctuations in the mean sea level, i.e., the average level of the sea surface, the data for which is derived from a series of continuous records of tidal oscillations over a considerably long period of time. Thus, the changes in sea level may also be termed as a relative change in sea level. During a relative rise in sea level, either the land or the sea surface may undergo upliftment or subsidence, or both may rise and fall at the same time.
- The major categories of change in sea level are mentioned below:

(i) Eustatic changes occur when the volume of sea water changes due to factors such as global warming and melting of ice sheets (rise in sea level) or ice ages (fall in sea level).

(ii) Tectonic changes occur due to a change in the level of land. These changes occur due to the following factors:

(a) Isostatic changes which take place due to addition or removal of load, e.g., during ice ages, landmass subsided due to the tremendous load exerted by the glacial ice; as a result there was an apparent rise in sea level. On the other hand, the landmass of Scandinavia is still rising as the glacial ice is being removed.

(b) Epeirogenic movement occurs due to broad scale tilting of continents which may result in the rise of one part of the continent in relation to the mean sea level even as the other part may subside causing an apparent rise in sea level.

(c) Orogenic movement is related to folding and flexuring (stretching of a part of the earth's crust) of the lithosphere which results in the formation of lofty mountains and an apparent fall in sea level.

- Therefore the phenomenon of sea level change may be summarised thus:

1. The rise in sea level is accompanied by the subsidence of land surface; rise in sea level may take place while the land remains stationary or the land rises at a slower rate than the sea level.
2. Sea level remains static, but the land subsides.
3. The sea level falls, but land subsides at a faster rate.

- Similarly, the fall in sea level may be due to: (1) sea level falling while the land surface rises or remains static or the land subsides at a slower rate; (2) no change in sea level but land moving upward; (3) the land surface rising at a faster rate than the rise of sea level.

Relevance of the Study of Sea Level Changes

- The study of sea level changes is important. It provides key evidences regarding climate change and also enables us to draw a benchmark for estimating the rates of tectonic upliftment in the past geological periods. Sea level directly influences the rate and pattern of erosional and depositional processes in the coastal areas. By studying the fluctuations of sea level it becomes possible to assess the suitability of coastal locations for industrial development. The fluctuations in sea level determine the availability of land, particularly in coastal areas, which are important for agricultural purposes. The submergence of land in future could be a disaster for the human civilisation as it may endanger our food security. By predicting climate change and the possible areas to be submerged under sea, it becomes possible for the low-lying countries to build coastal dykes and embankments. The task of mapping of areas likely to be affected by storm surges and periodic flooding becomes possible only if we know the likely areas to be affected by future sea level rise. The construction of tidal power generation units needs suitable locations. By identifying the areas of possible submergence in the near future it becomes possible for us to set up tidal power generation plants in suitable locations.

Evidence in Support of Sea Level Change

- The sea level changes in the Quaternary Period are reconstructed by using the following methods:
- Elevated shorelines, such as raised beaches, suggest a fall in sea level in that region in the past. The exact age of the changes in sea level is ascertained from the application of radiometric techniques on the materials found in those raised beaches.
- Submarine -canyons prove that once there was a relative rise in sea level because they are formed only in submerged conditions.
- Oxygen isotopes well preserved in the calcareous depositS of microfossils, found in the sedimentary deposits on the ocean floor, provide information about the sea level changes; the sea level change in the Quaternary period is known from such microfossil deposits. Evidence suggests that during the last few glaciations and interglacials, the average sea level stood at about 50 to 60 m below the present mean sea level.
- The continental shelves have either organic or inorganic deposits. Peat deposits are formed as a result of the decay of organic deposits in waterlog-0d conditions. Peat is formed in intertidal zones that'can be dated

radiometrically by applying carbon-14 technique. Therefore, peat deposits are also the source of valuable information about past sea level changes.

- We may conclude from the above mentioned evidence that, during the last glaciation (about 18,000 years ago), the sea level was 110 m to 140 m below the present sea level. Hence, large areas of the continental shelves were left dry. It was followed by a steady rise in sea level called Flandrian transgression. Between 18,000 and 8,000 years before present (BP—`present' being 1950), i.e., during the Holocene period, the sea level rose at a much faster rate (1 m/100 years). Although this rate of rise in sea level came to a standstill about 6000 to 5000 years BP, the history of sea level fluctuations during the past 10,000 years reveals that there were at least nine cold phases in Europe. Out of these, two phases have been demarcated precisely: the Medieval Advance (AD 1200 to 1400) and the Little Ice Age (AD 1550 to 1800).
- Evidence of pre-Quaternary sea level changes are obtained from various sources such as the sedimentary deposits of the continents. The depth of sediments indicates the possible duration of the submergence of the area where the sediments are deposited. The depth of the sediments can be known by determining their lithological and organic characteristics. If marine sediments are exposed subaerially due to the rise of land or fall in sea level, the change in sea level can be estimated by using fossil evidences. However, this technique only suggests regional sea level changes. The sea level changes of global extent can be ascertained from the study of sea level changes in different continents of the world. If the sea level fluctuations in different continents are synchronous, they may be assumed as a global sea level change. Moreover, the marine sediments found on stable cratonic terrain indicate sea level fluctuations in the past ages.
- Another approach of estimating sea level change is to plat the area of the continent where marine strata are found. The sea level changes in the pre-Quaternary period can also be estimated by tracing changes in the shorelines. Seismic evidence, gathered by drilling boreholes (because it is generally difficult to gathcr information from offshore sedimentary sequences by external observations), also helps us to understand the change in sediments at depth.
- The record of pre-Quaternary sea level change presented by the Exxon group shows global sea level changes from ay. Cretaceous Period to the present. It shows the long-term rise during the early Cretaceous Period was preceded by a prolonged period of generally low sea levels which had extended from the late Palaeozoic Era about 320 million years ago to the late Mesozoic Era about 150 million years ago. The study done by the Exxon group suggests that during the late Cretaceous, the sea level rose to a maximum 250 m above the present sea level. Most noteworthy are the dramatic falls in sea leVels during the Mesozoic and Cenozoic. The most rapid fall in sea level (about 150 m) took place in the late Oligocene Epoch.
- Mechanisms of the Change in Sea Level The fluctuations of sea level involve three basic mechanisms: changes in ocean water volume; changes in ocean basin volume; changes in the geoid, i.e., the shape of the earth..
- Changes in the volume of ocean water The present sea level would rise by about 60 to 75 m
- if the ice in Antarctica melts, whereas the Greenland ice cap would contribute about 5 m rise in sea level. It is assumed that, in such a case, the added load of ocean water would lead to the sinking of the ocean floor due to isostatic compensation. So the total rise of sea level would be about 40-50 m. However, the. isostatic adjustment of the land and the ocean is still not clear due to lack of data.
- The Antarctic ice-sheet was formed during the middle and late Tertiary and it resulted in the fall of the sea level. Abotit 3 to 4 million years ago, the continents of the northern hemisphere experienced the formation of extensive ice-sheets, the first time in geological history. As a result of this, the sea level dropped (as the total volume of ocean water was reduced).
- On the contrary, if the ice-sheet melts, the water returns to the ocean. Generally it is observed that in the initial stage of the melting of ice, the isostatic uplift is rapid, i.e., 3 m to 10 m per 100 years. The land surface rises when the ice load is removed by melting. But such a process of land upliftment is slow and takes several thousand years because of the viscous mantle and the overlying crustal block of low elasticity. Scandinavia, for example, is

still rising after the removal of ice deposited during the last Ice Age.

- Change in the volume of the ocean basin Changes in the volume of ocean basin and the resultant changes in sea level were an important event of the Mesozoic Era and the early Cenozoic Era. Such changes occur due to the following factors.
- (i) Changes in the volume of mid-oceanic ridges An important tectonic cause of sea level rise, changes in the volume of mid-oceanic ridges may occur due to periodic reorganisation of plate boundaries which cause variations in the total length of the ridge system. If the lithosphere is warm, the spreading rate increases causing an increase in ridge volume and vice versa. The sea level rises when the oceanic ridge increases in volume.
- Another factor is the change in the rate of sea floor spreading. Since the late Cretaceous Period, there has been a steady increase in the volume of mid-oceanic ridge. Since the ridge occupies about 12 per cent of the total volume of ocean water, any such change in the volume of the mid-oceanic ridge influence& the sea level to a great extent.
- (ii) Accumulation of sediments on the ocean floor Sediments are produced by the denudation of continents and are deposited on the ocean floor.
- The deposition of sediments may result in the subsidence of the ocean floor and the removal of sediments either through subduction or upliftment. If we do not take these two factors into consideration, there will be a rise in sea level due to the decreased volume of the ocean basin.
- Since the mid-Cretaceous Period, there has been a steady growth of carbonate accumulation in the ocean basins, mainly due to more active growth of carbonate-secreting marine organisms. It is assumed that the carbonate accumulation has resulted in a global rise of ocean floor by about 300 m and global rise of sea level by about 55 m even after isostatic adjustments.
- (iii) Impact of orogenesis As orogenesis causes shortening and thickening of continental crust and a reduction in the area of continents, the sea level falls as a result of an increase in the volume of the ocean basin. For example, if it is assumed that the Tibetan plateau is made of crustal layers of twice the average thickness, it will produce a fall of global sea level by about 26 m due to an. increased volume of ocean basin.
- (iv) Drying, out of small ocean basins Desiccation of ocean basins of smaller size may, lead to change in global sea level. K.J. Hsti in the early 1970s viewed that the presence of thick evaporite depasits in the sedimentary rocks of the
- Mediterranean Sea and the evidence of deep' submarine gorges from the mouths of rivers like the Nile and the Rhone prove that the entire Mediterranean sea was evaporated about 5 million years BP. The water evaporated from the Mediterranean Sea would have ultimately returned to oceans and produced a rise in sea level. According to the estimate of KJ. Hsti, there was a global sea level rise of 5 m even after an isostatic adjustment, i.e., subsidence of ocean floor by 10 m due to the increased load of water. It is to be mentioned that the Mediterranean Sea at that time was isolated from the rest of the oceans since the Strait of Gibraltar.was closed by a local upliftment.
- An analogous evidence of desiccation and sea level rise is found in the case of the southern part of the Atlantic Ocean in its nascent stage in the early Cretaceous period when the isolated ocean basin dried out. This led to a rise in sea level because the water of the southern part of the Atlantic Ocean returned to the water body of the surrounding oceans. Evidence in support of this event is found in the thick evaporite deposits. The global sea level rise probably reached 60 m after the desiccation of the south Atlantic.
- Geoidal Effect Hypothesis Isostatic movement of the earth's crust suggests vertical movement of the crust in response to the increased and decreased load on it. On the other hand, geoidal effects suggest crustal deformations as a result of continuous horizontal redistribution of mass within and between ocean basins of the world in response to an increase and decrease of load on ocean basins.
- A model developed in the 1970s by geophysicists and geomorphologists predicted six ocean basin zones which witnessed Holocene sea level change due to both isostatic and geoidal effects. However, sea level change due to geoidal impact is still not proved.

Marine/Resources and their Utilisation

* Marine resources are those resources found within ocean waters. These resources may be biotic or mineral.

Biotic Resources

* Of the biotic resources derived from the sea, human beings consume fish, crustaceans, molluscs, seaweeds and other edible forms of marine life. Marine animals provide oil, fur, leather, glue and cattlefeed. Marine plants and animals are used in curative medicine.
* Sea foods are of high nutritional value, and, given the limited land availability for agricultural expansion, are of great importance in meeting the food demands of humans in the future.
* Edible fish are of three main types, based on the location of habitat. Pelagic fish (mackerel, herring, anchovies, tuna) breed near the surface of seas. Demersal fish (haddock, cod, halibut, sole in the temperate region, and snapper and garoupa in tropical waters) feed on or near the sea bed of the continental shelf. Then there are the migratory anadromous fish (salmon) that live in the sea but move into fresh water of coastal rivers every year. [Fish resources are discussed in detail in the chapter Economic Geography, under `Resources'.]
* Whales are mammals of the ocean and have been caught not only for food but for industrial And medicinal purposes as well. Baleen whales are used as food by humans, in pet foods, in fertilizers, in flavouring, and as oil for margarine, soap and glycerin. Sperm whales provide products used in hardening agents, lubricants, and cosmetics.

* Another biotic resource is the squid. Squids show a great variety of form, and are found in all large seas from the Arctic to the tropical maritime regions. They occur near coasts as well as in the central part of the oceans to at least a depth of 5,000 metres. There are huge potential reserves of squids as only a limited area—northwestern Pacific, the Mediterranean, and the west coast of Africa—is at present exploited. However, squids are not commonly eaten in many parts of the world.

* Krill are small shrimp-like marine organisms inhabiting the Antarctic region. An important feed for whales, seals, squids and birds, krill stocks renew themselves rapidly; so increasing catches may not much affect the Antarctic ecosystem. However, since krill decompose rapidly, the catcher vessels must have technically advanced systems to enable quick processing or freezing of the catch.
* At the base of the food chain are the planktons—phytoplanktons and zoo-planktons. These are the food for many marine animal species. Benthos resources include animals such as crustaceans (prawn, shrimp, crab, lobster) and shellfish or molluscs (mussels, oysters).
* Aquaculture is well developed in Europe and Asia to breed oysters, mussels and clams. Benthos plants inClude algae. Algae such as sea lettuces are used in soups and salads and as flavouring. Kelp hai traditionally been used as winter fodder and to mulch fields along the northwest coast of US and Canada. Kelp is used in soups, or salted and pickled. It has been suggested that kelp can be

cultivated fer producing methane gas and used as an energy source by bioconversion

- There are many industrial uses for algae. Brown algae produce **algin** used as stabilisers in the paints industry, to strengthen ceramics, and to thicken jams. Red algae provide agar and carrageenan. Agar is an important medium for bacterial culture in research; it is also an ingredient in desserts and pharmaceutical products. **Carrageenan** is used as a stabiliser and emulsifier in ice-creams, salad dressings, puddings, and in cosmetics and medicines. Agar producing algae are harvested in Japan, Mexico, South America and Africa.

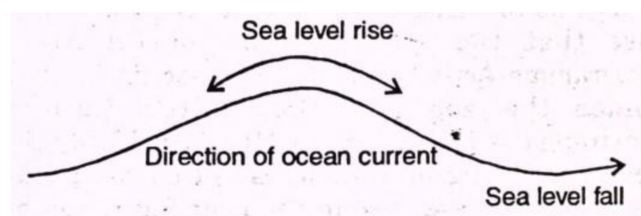
Jurisdiction over the Seas

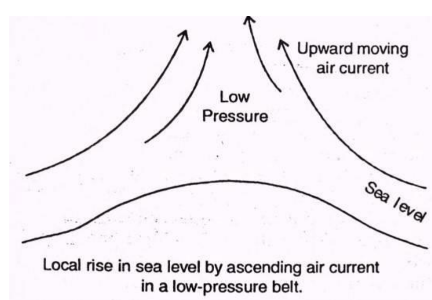
The issue of territorial rights of the seas has been discussed at **United Nations international conferences on the Law of the Sea**. *Four main decisions have been widely accepted since* **1978**.

Territorial waters *are those waters over which a state has full sovereignty and are now recognised as extendings for 19 km (12 miles) from the coast or from a base line drawn round an indented coast in such a way as to include fjords, estuaries and land between the mainland and offshore islands in the internal waters. Thus, countries like Indonesia can claim the waters between its islands. A further contiguous zone of 19 km is recognised in which the coastal state can take action against those who break the law within the true territorial waters. This, in other words, is a pursuit zone. An important feature is the recognition of a 320-km (200-mile)* **exclusive economic zone (EEZ)** *which starts at the same base line as the territorial waters.*

Within the EEZ the coastal state has the right to exploit all economic resources—fish, minerals, oil and gas and energy production. A modified arrangement is recognised on the continental shelf. States may claim rights to resources in the sea-bed for at least 320 km (200 miles), although the average width of the continental shelf is only 64 km. The state may extend these rights to the edge of the shelf—as much as 1280 km (800 miles) in some cases—though this does not include rights to the sea itself beyond the 320 km EEZ. Beyond all the zones in which individual countries can claim control are the high seas. The high seas are free for navigation by vessels of all nations. The oceans may also be used freely for the laying of submarine cables, and the airspace over them is also free. The oceans may also be freely fished by all nations, though some international agreements seek to- control overfishing, which endangers some species.

Short-Term Changes in Global Sea Level





- Short-term changes occur during a year. Commonly, seasonal variations of 5-6 cm in sea level are observed in a year. But the fluctuations of sea level reach 20-30 cm or more in almost all coastal areas of the world. Even if the causes of such short-term changes are not known, the fluctuations of sea level may be due to a complex interaction of the following factors:

- (i) Marine water density: Temperature and salinity control the density of sea water. Low temperature and high salinity produce high density of sea water and lower sea level. It is due to lower temperature and higher salinity that the eastern part of the Pacific Ocean has a sea level 30-50 cm higher than the Atlantic Ocean.
- (ii) Atmospheric pressure Low pressure results in higher local sea level and vice versa. The sea level rises locally in places of low pressure because water is sucked in by the upward moving airmass.
- (iii) Velocity of ocean currents Fast-flowing ocean currents when taking a curved path cause a rise in sea level on their outer fringes. Generally, a difference of 18 cm in sea level is observed between the two sides of a fast-flowing current.
- (iv)Ice formation and fall in sea level During winter the ocean water trapped in the icecaps of the northern and the southern hemispheres leads to a fall in sea level.
- (v) Piling up of water along windward coasts A local rise of sea level occurs in the coastal region as water is driven towards the coasts by an airmass, for example, the sea level rises in south and east Asia during the monsoon months due to landward movement of the airmass.
- The twentieth century has observed short-term global sea level rise due to the following factors.
- Global warming in the last century due to anthropogenic activities has resulted in thermal expansion of ocean water. So, the sea level has risen by about 10 to 15 cm in the past 100 years.
- Melting of ice-sheets in the Antarctica by about 3 per cent of its total volume of ice has, to some extent, contributed to global sea level rise.
- In the last century, about 15 per cent of the total volume of the Greenland ice cap melted. Besides these areas of ice-melt, other glaciers are also estimated ta have contributed about 48 per cent of the global sea level rise.

Long-Term Sea Level Changes

- Global sea level changes which exceed 100 m are possible only if the major ice-sheets melt or there are substantial changes in the volume of the world's mid-oceanic ridge. Other factors such as long-term changes in the geoid or global hypsometry, desiccation of small ocean basins etc. are considered to be of lesser importance. The effect of the melting of ice and changes-in the volume of mid-oceanic ridge cause global sea level change at a relatively faster rate than the latter.
- Explaining both the rates and magnitudes of the long-term sea level changes is not very easy because of rapid sea level changes on a global dimension which have occurred during the past few miflion years. The most remarkable of the past oceanic fluctuations is the Late Oligocene Epoch sea level fall which occurred about 30 million years BP. The sea level dropped to about 150 m at an average rate of 150 mm ka^{-1}. The rate of fall is slow if we consider the standards of glacioeustasy but too rapid if we take the factors such as the changes in the volume of the mid-oceanic ridge into consideration.
- An explanation of the long-term sea level change is difficult because of our lack of knowledge about the period of origin of ice-sheets in the Antarctica. However, evidence suggests that glaciation in Antarctica started between 45 and 20 million years BP. The most recent evidence provided by the Ocean Drilling Programme (of the US) suggests that glacial activity in east Antarctica began about 35 million years BP.
- Studies conducted on continental margins suggest that a bulk of them belong to

passive margins formed by the break-up of Gondwana and Laurasian plate. As these margins have cooled, and the sediments are deposited on such margins, they have been subsiding, leading to a rise in sea level. That is why sea level rise is being observed on most passive continental margins of the world over the past 100 million years.

Impact of Sea Level Fall

- Although the ice melt in the Antarctica hsts-not yet posed a serious danger for us, it may prove to be dangerous in the near future if the temperature of the atmosphere continues to increase.
- A fall in sea level may cause changes in the base levels of rivers. The rivers cut their new channels deeper than before. So a condition of rejuvenated landforms is found. The rivers curve deeper valleys on the rejuvenated land and canyons are formed even in the lower courses due to the rivers' adjustment with the new base level. Moreover, due to the extended shoreline, the drainage channels further extend towards the sea causing further lengthening of the rivers.
- A drop in sea level causes the death of coral reefs as the continental shelves on which they are formed are left dry. So, fresh coral reefs emerge along the fringe of dead corals.
- In places of shallow continental shelves, the fall in sea level leads to greater aridity in the continental hinterland due to reduced surface runoff.
- A fall in sea level in temperate and high latitude regions causes extension of ice caps and glacial tongues onto the continental shelves. In some cases, the glaciers have produced irregular topography like fjords, accumulation of debris on the shelves forming unsorted deposits of boulders etc. called glacial till.

Impact of Possible Rise in Sea Level

- A vast segment of the populated land, viz., the low-lying densely populated coastal areas, will be submerged. Even the small islands will be wiped out. Therefore, an estimated global population of about 1000 million will be affected.
- Immense damage may be caused to the coastal structures like ports, industrial establishments, etc.
- As a result of the rise in sea level, almost 33 per cent of the world's crop lands could be submerged.
- Accelerated coastal erosion may cause damage to and destruction of beaches, coastal dunes and bars. As a consequence, a vast section of the coastal land will remain unprotected against the direct attack of sea waves.
- Groundwater resources of the coastal regions will be severely affected by salinisation due to marine water intrusion.
- The ecosystem will suffer heavy damages as the deltas, coral atolls and reefs will be destroyed. New coral reefs on the outer fringe of the dead corals will be formed.
- One of the most direct impacts of sea level rise is the shrinkage in the drainage basin area. For example, during the late Cenozoic Era, which was a relatively warm interglacial phase, the drainage basins of the world experienced periodic submergence and major shifts in the drainage area. If the present rise in sea level continues, the same phenomenon may occur in the near future.
- It has been postulated by geomorphologists that during a certain period a beach and its adjacent sea floors adjust to storms and periods of low wave energy. When the sea level rises, the same beach undergoes erosion followed by the deposition of sediments on the adjacent sea floor. Thus, the sea level rises further as the sea floor is elevated by sediment deposition. The coastal region of northern New Zealand shows that during the twentieth century the mean sea level has risen by about 0.17 m to 0.35 m due to the above- mentioned factor.
- As a result of rise in sea level, the mouths of drainage basins will undergo submergence. This will lead to a

readjustment of the long-profiles of the rivers, which are likely to show a rise.

- The recent experiences suggest that the islands are the worst affected by the recent rise of sea level. Some of the affected islands are the Carteret Islands, located on the north-east of Papua New Guinea in the Pacific Ocean, and Tuvalu Islands, about 1000 km north of Fiji in the South Pacific.
- It was to check this phenomenon of sea level rise that the 'Oceans and Coastal Areas Programme Activity Centre' was set up in 1987 under the aegis of the United Nations Environment Programme (UNEP) to identify the countries facing maximum risk of submergence. Although sea level rise in the near future can be checked to some extent by taking steps against global warming, it is generally believed that it is inevitable: mankind has not yet reached the stage of a technological efficiency which can be entirely pollution-free and can cause minimal damages to the environment. Neither is there any international consensus regarding the prevention of global warming.

Law of the Sea and Marine Pollution

- Marine pollution refers to the emptying of chemicals or other particles into the ocean and its harmful effects. A critical problem arises when the potentially toxic chemicals stick to tiny particles and these are taken up by plankton and benthos animals which are deposit or filter feeders concentrating upward within foodchains. As animal feeds usually have a high fish meal or fish oil content, toxins can be found in consumed food items obtained from livestock and animal husbandry—in eggs, milk, butter, meat and margarine. A common route of entry of contaminants is the river where industrial wastes containing toxic chemicals flow into the water stream. When particles combine chemically, oxygen gets depleted and this causes estuaries to become anoxic, that is, deficient of oxygen.
- To curb marine pollution and regulate the use of the world's oceans by individual States, the nations of the world have come together to form two major conventions: one on dumping of wastes at sea (Convention on the Dumping of Wastes at Sea, to be replaced by the 1996 Protocol) and the other laying down rights and responsibilities of States in use of the oceans and their resources (United Nations Convention on Law of the Sea or UNCLOS).

Convention on Dumping of Wastes at Sea

- An inter-governmental conference on the Convention on the Dumping of Wastes at Sea met in London in November 1972 to adopt this instrument, the London Convention.
- The Convention has a global character and is aimed at international control and putting an end to marine pollution. The definition of dumping under the Convention relates to deliberate disposal at sea of wastes or other materials from vessels, aircraft, platforms and other man-made structures or disposal of the vessels or platforms themselves. 'Dumping' here does not cover wastes derived from the exploration and exploitation of sea-bed mineral resources. The provision of the Convention would not apply when there is a need to secure the safety life or of vessels in cases of force majeure.
- The Convention came into effect on August 30, 1975. The secretariat duties relating to it are overseen by the IMO.
- Details and Developments The articles aim to promote regional cooperation especially in the area of monitoring and scientific research. Parties have undertaken to designate an authority to manage permits, keep records and monitor the condition of the sea. There are wastes which cannot be dumped and others that require a special dumping permit. The criteria on issuing of this permit is also explained in an Annex that concerns the nature of the waste, characteristics of the dumping site and method of disposal of the waste.
- Certain important amendments were adopted by the Convention various times to deal with the emerging issues in the context of dumping of wastes in the oceans.
- The 1978 amendment, which came into effect on March 11, 1979, dealt with the incineration of wastes at sea. Another set of amendments adopted at the same time (October 1978) related to introduction of new procedures for dispute settlement.
- The 1980 amendments became effective on May 19, 1990. They give the procedures to be followed when permits are issued for special dumping. They state that permits must be issued only after considering whether there is enough of scientific information available to gauge the impact of dumping.
- The 1993 amendments, effective from February 20, 1994, banned dumping of low-level radioactive wastes into the seas. They phased out the dumping of industrial wastes by December 31, 1995 and called for an end to incineration of industrial wastes at sea.

- It is to be noted that dumping of low-level radioactive wastes and industrial wastes as well as incineration of wastes were earlier permitted by the Convention. But attitudes towards dumping have changed over the years and these have been reflected consistently in the amendments adopted. The changing approach, keeping in view the need of the times, led to the adoption of the 1996 Protocol on November 7, 1996.
- 1996 Protocol The Protocol, which became effective on March 24, 2006, replaces the 1972 Convention. It shows the major change in approach among the nations regarding the use of the sea as a place for dumping of waste materials-.
- Details of the Protocol (comparisons with the 1972 Convention included) The 1996 Protocol is much more restrictive as compared to the 1972 Convention that allowed dumping provided certain conditions were satisfied, the conditions varying depending on the magnitude of danger of the materials to the environment, even while blacklisting some materials from being dumped at all.
- Article 3 of the Protocol calls for appropriate preventive measures to be taken when wastes or other matter thrown into the sea are likely to cause harm "even when there is no conclusive evidence to prove a cause relation between inputs and their effects." The article states that "the polluter should, in principle, bear the cost of pollution". The Contracting Parties must ensure that the Protocol does not simply result in pollution being transferred from one part of the environment to another.
- Article 4 prohibits the Contracting Parties from dumping "wastes or any other matter with the exception of those listed in Annex 1". This Annex includes dredged material; sewage sludge; fish waste or material resulting from industrial fish processing operations; vessels and platforms or other man-made structures at sea; inert, inorganic geological material; organic material of natural origin; and bulky items like iron, steel, concrete and other similar unharmful materials for which the concern is mainly physical impact and it is.limited to those circumstances and where such wastes are generated in small islands with isolated peoples who have no access to other proper disposal options.
- Exceptions to the above are contained in Article 8 which allows dumping "in cases of force majeure caused by stress of weather, or in any case which constitutes a danger to human life or a real threat to vessels..."
- Article 5 prohibits incineration of wastes at sea (permitted by the 1972 convention but prohibited under the 1993 amendments).
- Article 6 states that "Contracting Parties shall not allow the export of wastes or other matter to other countries for dumping or incineration at sea". This reflects concern in recent years regarding export of wastes which cannot be dumped at sea under the 1972 Convention to Non-Contracting Parties.
- Article 9 calls upon the Parties to designate an appropriate authority to issue permits in accordance with the Protocol.
- Article 11 explains the compliance procedures which states that, no later than two years after the coming into effect of the Protocol, the "Meeting of Contracting Parties shall establish those procedures and mechanisms necessary to assess and promote compliance..."
- Article 16 contains procedures for settling disputes.
- Article 26 allows for a transitional period which enables Contracting Parties to phase in compliance with the convention over a five-year period. There are extended technical assistance provisions in this regard.
- The International Maritime Organisation (IMO) is responsible for Secretariat duties with respect to the Protocol.
- The Protocol has three annexes in all, two of them concerned with assessment of wastes and arbitral procedures.
- Amendments to the articles shall come into force on the 60th day after two-thirds of Contracting Parties 6hall have deposited an instrument of acceptance of the amendment with the IMO. Amendments to the annexes are adopted through a tacit acceptance procedure and they will be enforced not later than a hundred days after being adopted. The amendments are binding on all Contracting Parties except those who have clearly stated their non-acceptance.

2006 Amendments to the Protocol

- Adopted on November 2, 2006, the amendments were enforced on February 10, 2007. The amendments allow the dumping of carbon dioxide streams only when it is done into a sub-seabed 'geological formation; the streams have an overwhelming carbon dioxide content (they may also have incidental associated substances got from the source material and capture and sequestration processes used); and wastes or other matter are not added when disposing them. The amendments allow storage of carbon dioxide ($C0_2$) under the seabed but regulate the sequestration of $C0_2$ streams from $C0_2$ capture processes in sub-seabed geological formations. Parties agreed that guidance for conducting it should be developed within the earliest time possible. The amendments have created a basis in international environment law to regulate carbon capture and storage in subsealed geological formation in order to ensure their permanent isolation. It is part of the measures being considered to address climate change and ocean acidification like developing low carbon energy forms especially for sources of enormous CO_2 emissions (power plants, steel factories and cement works).

The United Nations Convention on Law of the Sea

- The UN Convention on Law of the Sea (UNCLOS) is an international agreement that defines the rights and responsibilities of nations where use of the oceans' waters by them is concerned. It was a result of the third UN Convention (conference) on Law of the Sea which was held from 1972 to 1982 and replaced four 1958 treaties. The UNCLOS specifies guidelines for businesses, the environment and management of marine natural resources.
- The UNCLOS came into force in the year 1994. In 1993, Guyana became the 60th state to sign the treaty. As of today; it has been signed by 155 countries and the European Community. The USA has signed the treaty but its senate is yet to ratify it.
- The UN Secretary General receives instruments of ratification and accession. The UN provides support for Convention meetings. However, the UN does not have a direct part in the implementation of the Convention. But organisations like the International Maritime Organisation and the International Whaling Commission have a role to play.
- The UNCLOS details a comprehensive regime of law and order in the seas and oceans of the world and lays down rules to govern use of the oceans and their resources. The full text of the Convention has 320 articles and nine annexes which deal with aspects like delimitation, control of environmental pollution, marine scientific research, economic and commercial activities in the seas, technology transfer and settlement of disputes between States with reference to ocean matters.
- History We can trace the beginning of UNCLOS to the 'freedom of the seas' concept of the seventeenth century which limited national rights to a specified belt of water extending from the coastlines of a nation. This was usually three nautical miles as laid down by the 'cannon shot' rule evolved by Cornelius Bynkershoek, a Dutch jurist. All waters that were beyond national boundaries were seen as 'international waters'. All nations were free to use these waters but these belonged to no one.
- Nations began to extend national claims in the early twentieth century. This was to make use of marine resources, protect fish stocks and enforce pollution controls. A conference was held at The Hague in 1930, called by the League of Nations. It, however, yielded no significant results. In 1945, US President Truman extended the US' control to all natural resources of its continental shelf. In the five years that followed, Argentina, Peru, Chile and Ecuador extended their rights to a distance of 200 nautical miles. Other countries extended their territorial seas up to 12 nautical miles.
- The UNCLOS held its first conference in 1956 significant opinions of their own. In 1973, the third conference was convened in New York. It used a consensus process rather than a majority vote to discourage groups of nation-states dominating negotiations. This conference lasted till 1982. The resulting convention, UNCLOS, came into force on November 16, 1994. It entered into force in accordance with its Article 308. It is the globally recognised regime today for dealing with all matters relating to the law of the sea.
- By 1967, 66 nations had established a 12-mile territorial limit and eight nations had set a 200-mile limit. Only 25 nations used the old 3-mile limit. Today, only a handful of countries use this 3-mile limit, among them Jordan, Palau and Singapore. Certain Australian islands, an area of Belize, some Japanese straits, some areas of Papua New Guinea and a few dependencies of the UK like Anguilla use the 3-mile limit.
- About UNCLOS The Convention introduced numerous provisions in significant areas, covering important issues in use and management of the world's oceans. The crucial issues covered include setting limits in various areas, navigation, archipelagic status and transit regimes, exclusive economic zones, continental shelf jurisdiction, deep seabed mining, the exploitation regime, protection of the marine environment, scientific research and dispute settlement.

Some of the key features of the UNCLOS are given below:

- Internal waters cover all water and waterways on the landward side of the baseline. (Normally, a sea baseline follows the low-water line, but when the coastline is deeply indented, has fringing islands or is highly unstable, straight baselines may be used.) The coastal state is free to set laws, regulate use, and use any resource. Foreign vessels have no right of passage within internal waters.
- Coastal states exercise sovereignty over their passing through waters in an expeditious and continuous manner, which is not "prejudicial to the peace, good order or the security" of the coastal state. Fishing, polluting, weapons practice, and spying are not "innocent", and submarines and other underwater vehicles are required to navigate^ on the surface and to show their flag. Nations can also temporarily suspend innocent passage in specific areas of their territorial seas, if doing so is essential for the protection of their security.
- Coastal States have sovereign rights over the continental shelf which may be defined as the natural prolongation of the land territory to the

continental margin's outer edge, or 200 nautical miles from the coastal state's baseline, whichever is greater. State's continental shelf may exceed 200 nautical miles until the natural prolongation ends, but it may never exceed 350 nautical miles, or 100 nautical miles beyond 2,500 metre isobath, which is a line connecting the depth of 2,500 metres. States have the right to harvest mineral and non-living material in the subsoil of its continental shelf, to the exclusion of others.

- The States must share with the international community part of the revenue derived from exploiting resources on the continental shelf extending beyond 200 miles. The Commission on [1] the Limits of the Continental Shelf would recommend to States on the shelf's outer boundaries when it extends beyond 200 nautical miles.
- special attention to protection and preservation of the marine environment (part XII, articles 192-237). It covers six main sources of ocean pollution: land-based and coastal activities, continental shelf drilling, potential seabed mining, ocean dumping, vessel-source pollution and pollution from or through the atmosphere.
- The limits of the territorial sea, the EEZ and continental shelf would be determined according to rules applicable to land territory; rocks that cannot sustain human habitation or economic life
- Beyond the 12 nautical mile limit there was a further 12 nautical miles or 24 nautical miles from the territorial sea baselines limit, the contiguous zone, in which a state could continue to enforce laws regarding activities such as smuggling or illegal immigration.
- Land-locked and geographically disadvantaged States can participate on an equitable basis in exploiting an appropriate part of the surplus of the living resources of the EEZs of coastal states of the same region or sub-region. Special protection should be accorded to highly migratory species of fish and sea mammals. In this context, it may be noted that the EEZs were introduced to halt the increasingly heated clashes over fishing rights, although oil was also becoming important. The success of an offshore oil platform in the Gulf of Mexico in 1947 was soon repeated elsewhere in the world, and by 1970 it- was technically feasible to operate in waters 4000 metres deep.
- States are bound to promote development and transfer of marine technology on "fair and reasonable terms and conditions", giving proper regard to legitimate interests.
- Aside from its provisions defining ocean boundaries, the Convention establishes general obligations for safeguarding the marine environment and protecting freedom of scientific research on the high, seas, and also creates an innovative legal regime for controlling mineral resource exploitation in deep seabed areas beyond national jurisdiction, through an International Seabed Authority.

Some Key Features of the UNCLOS Relating to Marine Pollution

- All States have the traditional freedoms of navigation, overflight, fishing and scientific research on the high seas. They must cooperate with each other to adopt measures to manage living resources and conserve them.
- States that border enclosed or semi-enclosed areas should cooperate in managing living resources, and in environmental and research policies and activities.
- States would be held liable for damage caused by violation of their international obligations to combat pollution of the seas.
- In the EEZ and on the continental shelf, all marine scientific research is subject to relevant coastal State's consent. The coastal states, in turn, are expected to grant consent for peaceful purposes to other States.The UNCLOS lays down the basic obligation of all countries to protect the marine environment and preserve it. All States are asked to cooperate, globally and regionally, to set up rules and standards and measures for the purpose. Coastal States have sovereign rights in a 200-nautical mile exclusive economic zone (EEZ) with regard to natural resources and some economic activities. It has rights to exercise jurisdiction over marine science research and environmental protection. It has sovereign rights over the continental shelf (the national area of the seabed), which can extend at least 200 nautical miles from the shore for its exploration and exploitation. Such jurisdiction allows coastal States to control and prevent marine pollution as a result of dumping, land-based sources or seabed activities subject to national jurisdiction or from the atmosphere where marine pollution from foreign vessels is concerned. Coastal States can exercise jurisdiction only for the enforcement of laws and regulation adopted in accordance with the UNCLOS or those that relate to "accepted international rules and standards" adopted through a competent international organisation—the International Maritime Organisation (IMO). Jt is the 'flag State'—the State, where a ship is registered and whose flag it flies—which must enforce the rule adopted for marine pollution from their vessels. This is especially a safeguard on the high seas—waters beyond the national jurisdiction of States.
- The UNCLOS allows enforcement powers to the 'port State'—the State which is a ship's destination. The port State can enforce any type of international rule or national regulations adopted in accordance with the Convention or applicable international rules as a condition for the foreign

vessels entering into their waters or their ports. This method has been developed in other conventions as well for enforcement of treaty obligations that deal with shipping standards, marine safety and combating pollution.

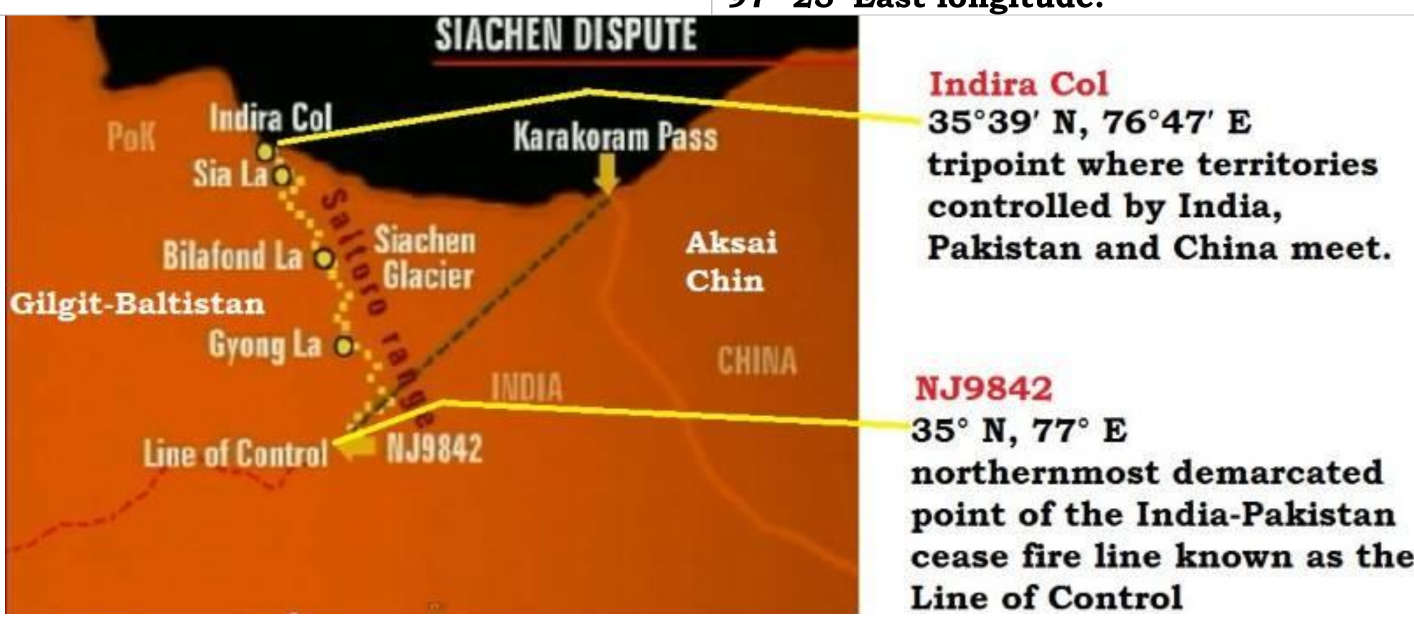
- To regulate seabed mining, there is the International Seabed Authority which has been established by the Convention. Through its Council, the organisation assesses the potential environmental effects of deep seabed mining operations; recommends changes; formulates rules; sets up a monitoring pro amme; and suggests issuance of emergency ora^rs to combat serious damage to the marine environment. States are held liable for damage caused by their own enterprise or contractors under their jurisdiction.
- With time, the UN's involvement with the law of the sea has expanded owing to increasing awareness of the ocean-related problems and emergence of an understanding among States that global problems are inter-related. We may here mention the efforts done at major international conferences like the UN Conference on Environment and Development (UNCED) at Rio de Janeiro, Brazil that emphasised on th$ protection and preservation of the oceans' environment in harmony with the. rational use of their living resources. An intergovernmental conference was held under UN auspices to resolve the conflict between coastal states and distant-water fishing States over straddling and migratory fish stocks in areas adjacent to the 200 nautical mile EEZs. A result of their conference was the Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks adopted in 1995 that introduced new measures in environmental and resource protection. States have been obliged to assume a precautionary approach to exploitation of fisheries. Port States have been given expanded powers to ensure that they properly manage fisheries resources.

Indian Geography

In this post: Indian Geography: India – Geographical Extent, Frontiers – Border with Neighbors.

India As A Geographical Unit

East-West Extent of Main Land India (Including Pak occupied Kashmir-POK):	**68° 7' east to 97° 25' east longitude**
South-North Extent of Main Land India:	**8° 4' north to 37° 6' north latitude**
Locational Extent:	**8° 4' N to 37° 6' N latitude and 68° 7' E to 97° 25' East longitude.**



PRESENT MAP OF JAMMU & KASHMIR

- The southernmost point of the country is the **Pygmalion Point** or **Indira Point** is located at **6° 45' N latitude**.
- North-south extent from **Indira Col in Kashmir to Kanniyakumari is 3,214 km.**
- East-west width from the **Rann of Kachachh to Arunachal Pradesh is 2,933 km.**

- With an area of **32,87,263 sq km**, India is the **seventh largest** country of the world.
- India accounts for about **2.4 per cent** of the total surface area of the world.
- The Tropic of Cancer passes through the middle of the country dividing it into two latitudinal halves.
- The area to the north of Tropic of Cancer is nearly **twice** the area which lies to the south of it.
- South of 22° north latitude, the country tapers off over 800 km into the Indian Ocean as a peninsula.

East-West time difference is nearly 2 hrs.

- The earth moves [rotation and revolution] around its axis through 360° in 24 hours. Thus, a difference of 1° longitude will make a difference of 4 minutes in time.
- Therefore the difference of local time between western-most point and eastern-most point is 30 x 4 = 120 minutes or 2 hours.

Top 10 Largest Countries in the World by Area

Rank	Country	Capital City	Continent	Area (square km)
1	Russia	Moscow	Europe	17098242
2	Canada	Ottawa	North America	9984670
3	United States of America	Washington DC	North America	9826675
4	China	Beijing	Asia	9596961
5	Brazil	Brasilia	South America	8514877
6	Australia	Canberra	Oceania	7741220
7	India	New Delhi	Asia	3287263
8	Argentina	Buenos Aires	South America	2780400
9	Kazakhstan	Astana	Asia	2724900
10	Algeria	Algiers	Africa	2381741

India, Tropical or Temperate Country?

- The temperate part (north of Tropic of Cancer) is twice the area of tropical part.
- But India has always been treated as a tropical country for two different reasons – physical and cultural.

Physical Geographical Reasons

- The country is separated from the rest of Asia by Himalayas.
- Its climate is dominated by the **tropical monsoons** and the temperate air masses are blocked by Himalayas.
- Entire area south of the Himalayas is essentially tropical from climatic point of view: Although the night temperatures in Winter at several places in North India may come down to the level of those prevailing in temperate lands, yet **clear skies** and intense insolation raise the day temperatures to a tropical level.

Cultural Geographical Reasons

- Settlements, diseases, agricultural and primary economic activities are all tropical in nature.

It is primarily because of Himalayas that India is a tropical country.

India's Frontiers

Data from Ministry Of Home Affairs (Department Of Border Management)

- India has **15106.7 Km** of land border running through 92 districts in 17 States and a coastline of **7516.6 Km [6100 km of mainland coastline + coastline of 1197 Indian islands]** touching 13 States and Union Territories (UTs).

Name of the country	Length of the border (in Km)
Bangladesh	4,096.7
China	3,488
Pakistan	3,323
Nepal	1,751
Myanmar	1,643
Bhutan	699
Afghanistan	106
Total	**15,106.7**

- Barring **Madhya Pradesh, Chhattisgarh, Jharkhand, Delhi and Haryana**, all other States in the country have one or more international borders or a coastline and can be regarded as **frontline States** from the point of view of border management.
- India's longest border is with ***BANGLADESH*** while the shortest border is with Afghanistan.
- The length of India's land borders with neighboring countries is as under

Border with China

- This is the **second longest** border of India, next only to its border with Bangladesh.
- Five Indian states, namely Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh touch the Indian boundary with China.
- The Sino-Indian border is generally divided into three sectors namely : (i) the Western sector, (ii) the Middle sector, and (iii) the Eastern sector.

The Western Sector

- Separates Jammu and Kashmir state of India from the Sinkiang (Xinjiang) province of China.
- The western sector boundary is largely the outcome of the British policy towards the state of Jammu and Kashmir.
- China claims the **Aksai Chin district**, the **Changmo valley, Pangong Tso** and the **Sponggar Tso** area of north-east Ladakh as well as a strip of about 5,000 sq km down the entire length of eastern Ladakh.
- China also claims a part of **Huza-Gilgit area** in North Kashmir *(ceded to it in 1963 by Pakistan).*

The Middle Sector

- Two Indian states of Himachal Pradesh and Uttarakhand touch this border.

The Eastern Sector

- The 1,140 km long boundary between India and China runs from the eastern limit of Bhutan to a point near ***Talu-Pass*** at the trijunction of India, Tibet and Myanmar.
- This line is usually referred to as the **Mc Mahon Line** after Sir Henry Mc Mahon, then foreign secretary of British India, who

negotiated the boundary agreement between Great Britain and Tibet at **Shimla accord in 1913-14.**

The India-Nepal Boundary

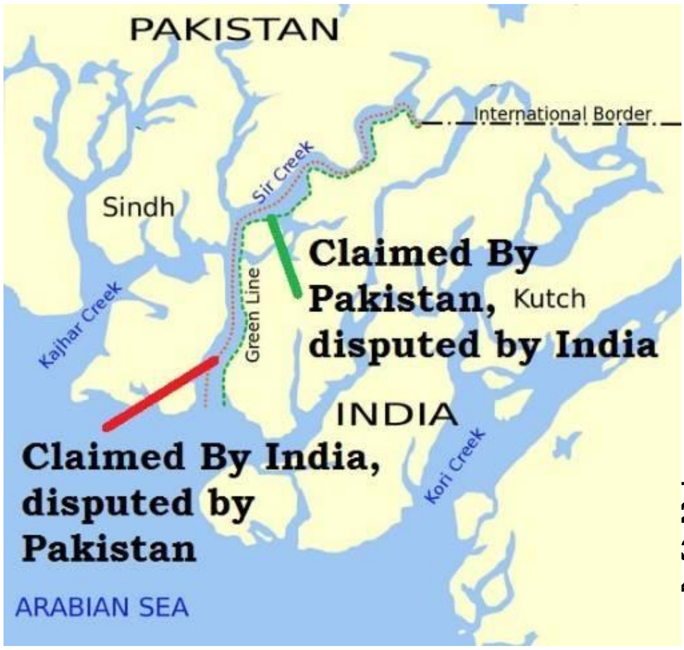
- Five states of India, namely Uttarakhand, Uttar Pradesh, Bihar, West Bengal and Sikkim touch the Nepalese border with India. The border is a **porous** one with unrestricted movement of goods and people between Indian and Nepal.
- Major portion of Indo-Nepalese border runs in the east-west direction almost along the foothill of the **Shiwalik Range.**

The India-Bhutan Boundary

- Quite peaceful border and there is no boundary dispute between the two countries.

The Indo-Pakistan Boundary

- The Indo-Pakistan boundary is the result of partition of the country in 1947 under the **Radcliffe award** of which **Sir Cyril Radcliffe** was the chairman.
- Jammu and Kashmir, **Sir Creek** are the major disputed regions.



The India-Bangladesh Border

- India's 4,096 km long border with Bangladesh is the longest.
- This boundary has been determined under the **Radcliffe Award** which divided the erstwhile province of Bengal into two parts.

India-Myanmar Boundary

- This boundary runs roughly along the watershed between the Brahmaputra and **Ayeyarwady [Irrawaddy].**
- It passes through thickly forested regions, with Mizo Hills, Manipur and Nagaland on the Indian side and Chin Hills, Naga Hills and Kachin state on the Myanmar side.

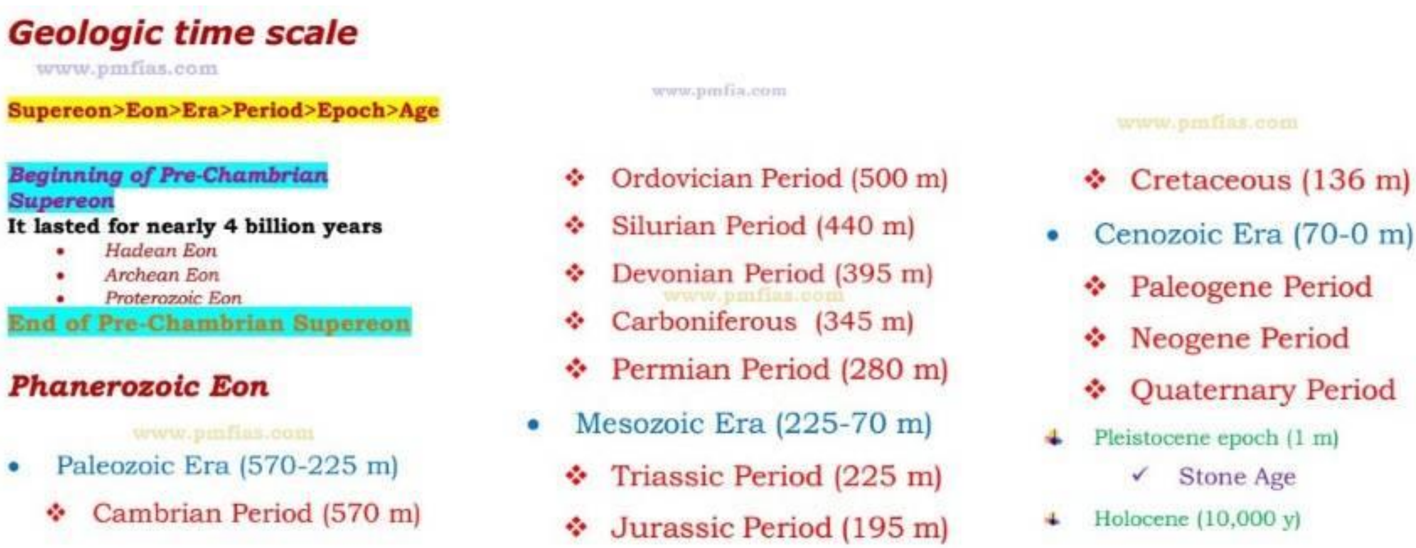
India-Sri Lanka Boundary

- India and Sri Lanka are separated from each other by a narrow and shallow sea called **Palk Strait.**
- **Dhanushkodi** on the Tamil Nadu coast in India is only 32 km away from **Talaimanar** in Jaffna peninsula in Sri Lanka. These two points are joined by a group of islets forming **Adam's Bridge.**

In this post: Archaean Rock System, Archaean Gneisses and Schists, Dharwar System, Purana Rock System, Cuddapah System, Vindhyan System, Dravidian Rock System, Carboniferous rocks, Carboniferous Coal, Aryan Rock System, Gondwana System, Gondwana Coal, Jurassic System, Deccan Trap, Tertiary System etc..

Rock System Based on Geological History Of India

1. ***The Archaean Rock System.***
2. ***The Purana Rock System.***
3. ***The Dravidian Rock System.***
4. ***The Aryan Rock System.***



Archaean Rock System (Pre-Cambrian Rocks)

- Rocks formed prior to the Cambrian system.
- The Archaean rock system includes:

Archaean Gneisses and Schists [4 Billion Years]

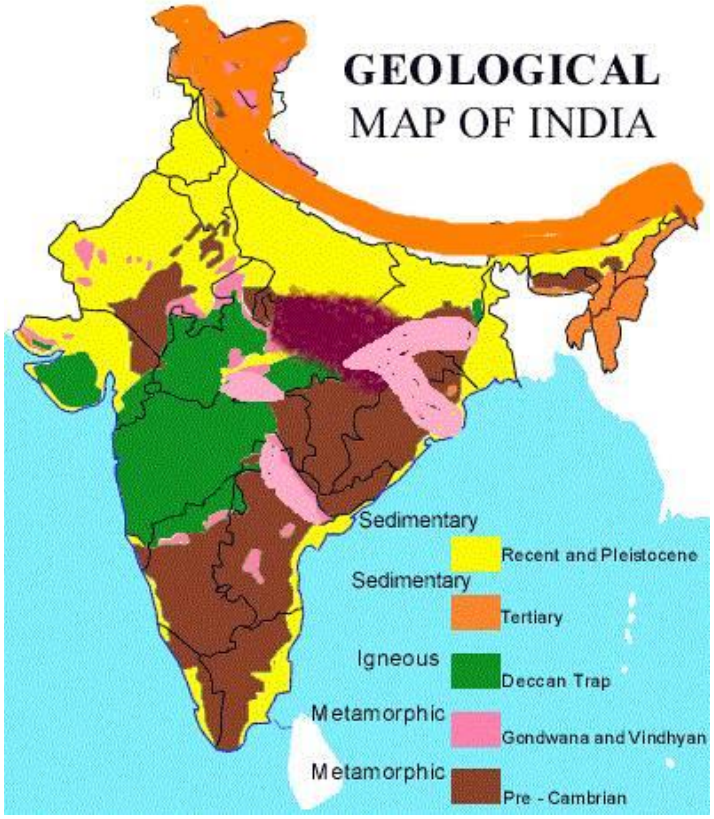
Gneiss == Mineral composition varies from granite to gabbro.

Schists == mostly crystalline, include mica, talc, hornblende, chlorite, etc.

These rocks are:

- **Oldest rocks** [pre-Cambrian era] [formed about 4 billion years ago].
- Rocks formed due to solidification of molten magma – the earth's surface was very hot then.
- Known as the **'Basement Complex'** [They are the oldest and forms the base for new layers]
- Azoic or unfossiliferous,
- Foliated (consisting of thin sheets),
- Thoroughly crystalline (because they are volcanic in origin),

- Plutonic intrusions (volcanic rocks found deep inside).



Dharwar System [4 – 1 Billion Years]

- Formation period ranges from 4 billion years ago to – 1 billion years ago.
- Highly **metamorphosed sedimentary** rock-system. [formed due to metamorphosis of sediments of Archaean gneisses and schists].
- They are the **oldest metamorphosed rocks**.
- Found in abundance in the Dharwar district of Karnataka.
- **Economically the most important rocks** because they possess valuable minerals like high grade iron-ore, manganese, copper, lead, gold, etc.

Purana Rock System (1400 – 600 Million Years)

- Includes two divisions: the **Cuddapah System** and the **Vindhyan System**.

Cuddapah System

- Unfossiliferous clay, slates, sandstones and limestones was deposited in **synclinal basins** [depression between two folds {Fold mountain}].
- Outcrops best observed in Cuddapah district of Andhra Pradesh.
- These rocks contain ores of iron, manganese, copper, cobalt, nickel, etc.
- They contain large deposits of cement grade limestones.

Vindhyan System (1300-600 million years)

- This system derives its name from the great Vindhyan mountains.
- The system comprises of ancient sedimentary rocks (4000 m thick) superimposed on the Archaean base.
- Mostly Unfossiliferous.
- Large area of this belt is covered by the **Deccan trap.**
- The Vindhayan system have ***diamond bearing*** regions from which **Panna** and **Golconda diamonds** have been mined.
- It is **devoid of metalliferous minerals** but provides large quantities of durable stones, ornamental stones, limestone, pure glass making sand etc..

Dravidian Rock System (Palaeozoic)

- Formed about **600 – 300 million years ago**.
- Found in the **Extra Peninsular region (Himalayas and Ganga plain)** and are very rare in Peninsular India. [The name 'Dravidian' doesn't mean they are found in South India]
- Abundant fossils.
- The rocks of Cambrian, Ordovician, Silurian, Devonian and Carboniferous periods are fall under Dravidian system. (All these are not important, only **Carboniferous** is important)

Carboniferous rocks (350 million years)

- The Carboniferous rocks (350 million years) comprise mainly of limestone, shale and quartzite.

- **Mount Everest** is composed of Upper Carboniferous limestones.
- **Coal formation** started in the Carboniferous age.
- Carboniferous in geology means **coal bearing**. [most of the coal found in India is not of Carboniferous period; High quality coal of **Great Lakes Region-USA, U.K and Ruhr** region is Carboniferous coal].

Aryan Rock System

- Upper **Carboniferous to the Recent**.

Gondwana System

- The **Gondwana System** [derives its name **Gonds**, the most primitive people of Telangana and Andhra Pradesh]
- They are deposits laid down in **synclinal troughs** on ancient plateau surface.
- As the sediments accumulated, the loaded troughs subsided.
- Fresh water and sediments accumulated in these trough and terrestrial plants and animals thrived.
- This happened since Permian period (250 million years ago).

Gondwana Coal

- Gondwana rocks contain nearly **98 per cent of India's coal reserves**.
- Gondwana coal is **much younger** than the Carboniferous coal and hence it's carbon content is low.
- They have rich deposits of iron ore, copper, uranium and antimony also.
- Sandstones, slates and conglomerates are used as building materials.

Jurassic System

- The marine transgression in the latter part of the Jurassic gave rise to thick series of **shallow water deposits** in Rajasthan and in Kuchchh.
- Coral limestone, sandstone, conglomerates and shales occur in Kuchchh.
- Another transgression on the east coast of the Peninsula is found between **Guntur and Rajahmundry.**

Deccan Trap

- Volcanic outburst over a vast area of the Peninsular India from the end of the **Cretaceous** till the beginning of the **Eocene** gave rise to Deccan Traps.
- **Basaltic lava** flowed out of fissures covering a vast area of about **ten lakh sq km.**
- These volcanic deposits have flat top and steep sides and therefore called **'trap'** meaning a 'stair' or 'step' in Swedish.
- The process of weathering and erosion (denudation) since millions of years has reduced the Deccan Trap to almost half of its original size.
- Present Deccan Trap covers about **5 lakh sq km** mainly in parts of Kuchchh, Saurashtra, Maharashtra, the Malwa plateau and northern Karnataka.
- Thickness of the Deccan Traps is 3,000 metres along the west which is reduced to 600-800 metres towards the south, 800 metres in Kuchchh and only 150 metres at the eastern limit.
- The weathering of these rocks for a long time has given birth to **black cotton soil** known as **'regur'**.

The Deccan Trap has been divided into three groups:

Group	Found in	Inter-trappean beds	Layers of volcanic ash
The Upper Trap	Maharashtra and Saurashtra	Present	Present
The Middle Trap	Central India and Malwa	Very rare to absent	Present
The Lower Trap		Present	Very rare to absent

Tertiary System

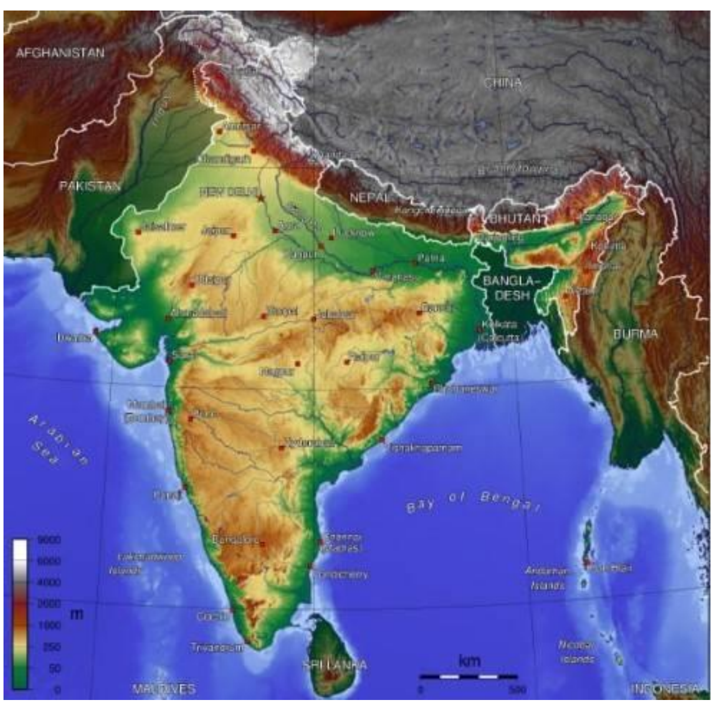
- Eocene to Pliocene about 60 to 7 million years ago.

- The tertiary is the most significant period in India's geological history because the **Himalayas** were born and India's present form came into being in this period.

In his post: Major Physical Divisions of India – Himalayas - Himalayan Ranges: Shiwaliks or outer Himalayas, Lesser or Middle Himalayas, Greater Himalayas, Trans-Himalayas or Tibetan Himalayas and Eastern Hills or Purvanchal.

Major Physical Divisions of India

1. The Himalayas (young fold mountains),
2. Indo-Gangetic Plain (monotonous topography – featureless topography),
3. The Peninsular Plateau (one of the most stable landmasses; one of the oldest plateaus of the world),
4. Coastal Plains (Sediments due to fluvial action).
5. The Indian Islands [Coral Islands == coral reef built up on atolls – Lakshadweep. Tectonic == Andaman and Nicobar Islands – Interaction between Indian Plate and Eurasian plate] and



Peninsular Plateau

- Includes the entire south India, central India, Aravalis, Rajmahal hills, Meghalaya plateau, Kuchchh-Kathiawar region (Gujarat) etc..
- It is the oldest and the most **stable** landmass of India.

Himalayas

- Includes the Himalayas, Purvanchal and their extensions Arakan Yoma (Myanmar) and Andaman and Nicobar Islands (but we will consider these as islands only).
- It is the youngest and **highly unstable** landmass of India. [Continent – Continent Convergence]
- Tectonic movements are very common.

Indo-Gangetic Plain

- Between Peninsular and Himalayan region.
- Most youthful, monotonous [lack of change or variety] region prone to tectonic forces.

Coastal Plains

- Eastern Coastal Plains and Western Coastal Plains.
- Formed due to consolidation of sediments brought by rivers (fluvial deposits).
- Highly **stable** just like peninsular plateau.

Indian Islands

- Two major groups – Lakshadweep and, Andaman and Nicobar islands.
- Lakshadweep [Hotspot] are group of atolls occupied by coral reefs. No significant volcanism or tectonic activity in recent past. Highly vulnerable to sea-level rise.
- Andaman and Nicobar islands – Continuation of Arakan Yoma. Has active volcanoes and is tectonically active.

Type of Topography	Extent in %
Mountainous (more than 2135 m above sea level)	**10.7**
Hilly area (305 – 2135 m above sea level)	**18.6**
Plateau (305 – 915 m above sea level)	**27.7**
Plains	**43**

Division of the Himalayas

Formation of Himalayas explained in Continent – Continent Convergence.

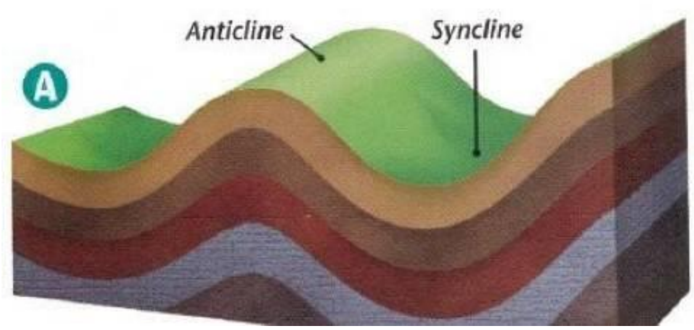
1. **Shiwaliks or outer Himalayas**
2. **Lesser or Middle Himalayas**
3. **The Greater Himalayas**
4. **The Trans-Himalayas – Tibetan Himalayas.**
5. **The Eastern Hills – Purvanchal: A chain of hills in North-East India.**

Himalayan Ranges

- Series of several **parallel or converging ranges**.
- The ranges are separated by deep valleys creating a highly **dissected topography** [(of a plateau or upland) divided by a number of deep valleys].
- The **southern slopes have steep gradients** and northern slopes have comparatively gentler slopes. *[Scaling Mount Everest is less hectic from the northern side. But China puts restrictions so climbers take the steeper southern slopes from Nepal]*
- Most of the Himalayan ranges fall in India, Nepal and Bhutan. The northern slopes are partly situated in Tibet (trans-Himalayas) while the western extremity lies in Pakistan, Afghanistan and Central Asia.
- Himalayas between Tibet and Ganga Plain is a succession of three parallel ranges.

Shiwalik Range

- Also known as **Outer Himalayas**.
- Located in between the Great Plains and **Lesser Himalayas**.
- The altitude varies from **600 to 1500 metres**.
- Runs for a distance of 2,400 km from the **Potwar Plateau** to the **Brahmaputra valley**.
- The southern slopes are steep while the northern slopes are gentle.
- **The width of the Shiwaliks varies from 50 km in Himachal Pradesh to less than 15 km in Arunachal Pradesh.**
- They are almost unbroken chain of low hills except for a gap of 80-90 km which is occupied by the valley of the **Tista River and Raidak River**.
- Shiwalik range from North-East India up to Nepal are covered with thick forests but the forest cover decreases towards west from Nepal (The quantum of rainfall decreases from **east to west** in Shiwaliks and Ganga Plains).
- The southern slopes of Shiwalik range in Punjab and Himachal Pradesh are almost devoid of forest cover. These slopes are highly dissected by seasonal streams called **Chos.**
- Valleys are part of synclines and hills are part of anticlines or antisynclines.



Formation (Formation of Himalayas already explained)

- Shiwaliks were formed last of all the ranges (2-20 million years ago).
- The Shiwaliks are consolidated sands, gravels and conglomerate deposits [Alluvial fans] which were brought by the rivers flowing from the higher ranges.
- These deposits were **folded and hardened** due to compression offered by the northward movement of Indian plate.

The Shiwaliks are known by different names in different areas

Region	Name of Shiwaliks
Jammu Region	Jammu Hills
Dafla, Miri, Abor and Mishmi Hills	Arunachal Pradesh

The Dhang Range, Dundwa Range	**Uttarakhand**
Churia Ghat Hills	**Nepal**

Explain the formation of Duns (Duras)

- Shiwalik Hills were formed by the accumulation of conglomerates (sand, stone, silt, gravel, debris etc.).
- These conglomerates, in the initial stages of deposition, obstructed the courses of the rivers draining from the higher reaches of the Himalayas and formed **temporary lakes.**
- With passage of time, these temporary lakes accumulated more and more conglomerates. The conglomerates were well settled at the bottom of the lakes.
- When the rivers were able to cut their courses through the lakes filled with conglomerate deposits, the lakes were drained away leaving behind plains called **'duns' or 'doons'** in the west and **'duars'** in the east.
- **Dehra Dun in Uttarakhand** is the best example [75 km long and 15-20 km wide]
- Kotah, Patli Kothri, Chumbi, Kyarda, Chaukhamba, Udhampur and Kotli are other important duns.

Middle or the Lesser Himalaya

- In between the Shiwaliks in the south and the Greater Himalayas in the north.
- Runs almost parallel to both the ranges.
- It is also called the **Himachal or Lower Himalaya**.
- **Lower Himalayan** ranges are 60-80 km wide and about 2400 km in length.
- Elevations vary from **3,500 to 4,500 m** above sea level.
- Many peaks are more than 5,050 m above sea level and are snow covered throughout the year.
- **Lower Himalaya**s have **steep, bare southern slopes [steep slopes prevents soil formation]** and more gentle, forest covered northern slopes.
- In Uttarakhand, the Middle Himalayas are marked by the **Mussoorie** and the **Nag Tibba** ranges.
- The **Mahabharat Lekh**, in southern Nepal is a continuation of the Mussoorie Range
- East of the Kosi River, the Sapt Kosi, Sikkim, Bhutan, Miri, Abor and Mishmi hills represent the lower Himalayas.
- The Middle Himalayan ranges are more friendly to human contact.

Majority of the Himalayan hill resorts like Shimla, Mussoorie, Ranikhet, Nainital, Almora and Darjeeling, etc. are located here.

Important ranges of Lesser Himalayas	Region
The Pir Panjal Range	**Jammu and Kashmir (They are to the south of Kashmir Valley)**
The Dhaola Dhar Range	**Himachal Pradesh**
The Mussoorie Range and The Nag Tiba Range	**Uttarakhand**
Mahabharat Lekh	**Nepal**

The Pir Panjal range

- The **Pir Panjal range** in Kashmir is the longest and the most important range.
- It extends from the **Jhelum river** to the **upper Beas** river for over 300 km.
- It rises to 5,000 metres and contains mostly volcanic rocks.

Passes in Pir Panjal

- Pir Panjal Pass (3,480 m), the Bidil (4,270 m), Golabghar Pass (3,812 m) and Banihal Pass (2,835 m).
- The **Banihal Pass** is used by the Jammu-Srinagar highway and Jammu-Baramula railway.
- The **Kishanganga**, the **Jhelum** and the **Chenab** cut through the range.
- Southeast of the Ravi, the Pir Panjal continues as **Dhaola Dhar range**, passing

through Dalhousie, Dharmshala, and Shimla.

Important Valleys

- Between the Pir Panjal and the Zaskar Range of the main Himalayas, lies the valley of Kashmir. (average elevation is 1,585 m above mean sea level)
- The synclinal basin of the valley is floored with alluvial, lacustrine [lake deposits], fluvial [river action] and glacial deposits. {Fluvial Landforms, Glacial Landforms}
- Jehlum River meanders through these deposits and cuts a deep gorge in Pir Panjal through which it drains. (Kashmir is like a basin with very few outlets)
- In Himachal Pradesh there is **Kangra Valley**. It is a ***strike valley*** and extends from the foot of the Dhaola Dhar Range to the south of Beas.
- On the other hand, the **Kulu Valley** in the upper course of the Ravi is **transverse valley**.

Strike valley vs. Transverse valley

A valley perpendicular to the slope or parallel to the ridge [also called as longitudinal valley]

In contrast, transverse streams cut valleys parallel to the slope (along the dip).

The Great Himalaya

- Also known as **Inner Himalaya, Central Himalaya or Himadri**.
- Average elevation of 6,100 m above sea level and an average width of about 25 km.
- It is mainly formed of the central crystallines (granites and gneisses) overlain by metamorphosed sediments [limestone]. {Rock System}
- The folds in this range are asymmetrical with steep south slope and gentle north slope giving 'hog back (a long, steep hill or mountain ridge)' topography.
- This mountain arc convexes to the south just like the other two.
- Terminates abruptly at the **syntaxial bends**. One in the **Nanga Parbat** in north-west and the other in the **Namcha Barwa** in the north-east.
- This mountain range boasts of the tallest peaks of the world, most of which remain under perpetual snow.

Regional name of Mount Everest	**Region**
Sagarmatha (The Goddess of the Sky)	Nepal
Chomlungma (Mother of the World)	China (Tibet)

- Mount Everest was first located by George Everest, the then Surveyor General of India in 1841 and in 1852 it was established as the highest peak of the world by the Great Trigonometrical Survey of India.

Passes in the Greater Himalayas

- The passes because they are generally higher than 4,570 m above sea level and are snowbound for most of the year.

State	**Passes of Greater Himalayas**
Jammu and Kashmir	Burzil Pass Zoji La [La means pass]

Himachal Pradesh	Bara Lacha La Shipki La [The Hindustan-Tibet Road connecting Shimla with Gartok in Western Tibet]
Uttarakhand	Thaga La Niti Pass Lipu Lekh
Sikkim	Nathu La Jelep La [important trade route connecting Kalimpong (near Darjeeling) with Lhasa in Tibet, passes through Jelep La (4,386 m)]

The Trans Himalayas

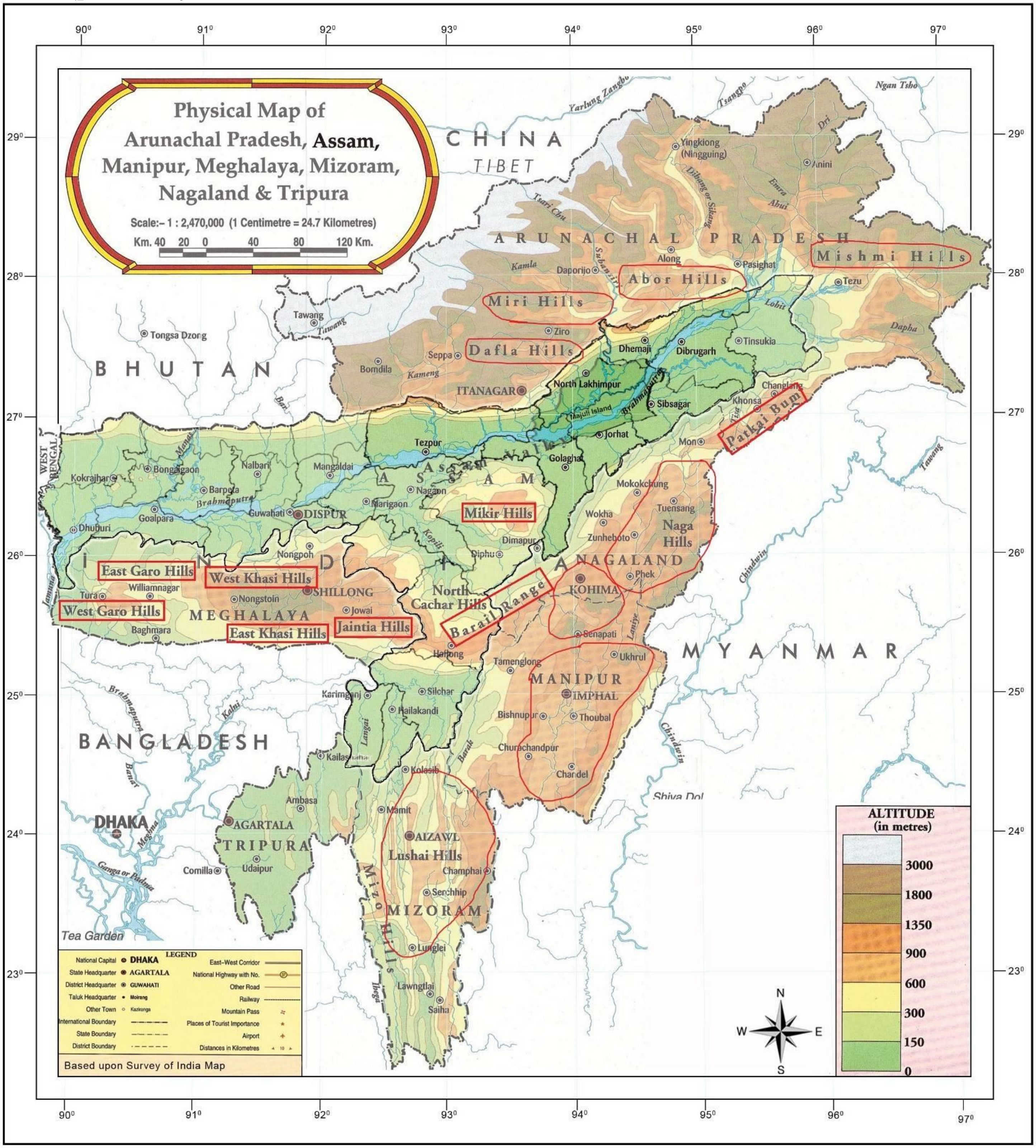
- The Himalayan ranges immediately north of the Great Himalayan range.
- Also called the **Tibetan Himalaya** because most of it lies in Tibet.
- The **Zaskar**, the **Ladakh**, the **Kailas** and the **Karakoram** are the main ranges.
- It stretches for a distance of about 1,000 km in east-west direction.
- Average elevation is 3000 m above mean sea level.
- The average width of this region is 40 km at the extremities and about 225 km in the central part.
- The **Nanga Parbat (8126 m)** is an important range which is in The Zaskar Range.
- North of the Zaskar Range and running parallel to it is the Ladakh Range. Only a few peaks of this range attain heights of over 6000 metres.
- The Kailas Range (**Gangdise in Chinese**) in western Tibet is an offshoot of the Ladakh Range. The highest peak is Mount Kailas (6714 m). **River Indus originates from the northern slopes of the Kailas range.**
- The northern most range of the Trans-Himalayan Ranges in India is the Great **Karakoram Range** also known as the **Krishnagiri range**.
- **Karakoram Range** extends eastwards from the Pamir for about 800 km. It is a range with lofty peaks [elevation 5,500 m and above]. It is the **abode of some of the greatest glaciers** of the world outside the polar regions.
- Some of the peaks are more than 8,000 metre above sea level. **K2 (8,611 m)[Godwin Austen or Qogir]** is the second highest peak in the world and the highest peak in the Indian Union.
- The Ladakh Plateau lies to the north-east of the Karakoram Range. It has been dissected into a number of plains and mountains [Soda Plains, Aksai Chin, Lingzi Tang, Depsang Plains and Chang Chenmo]

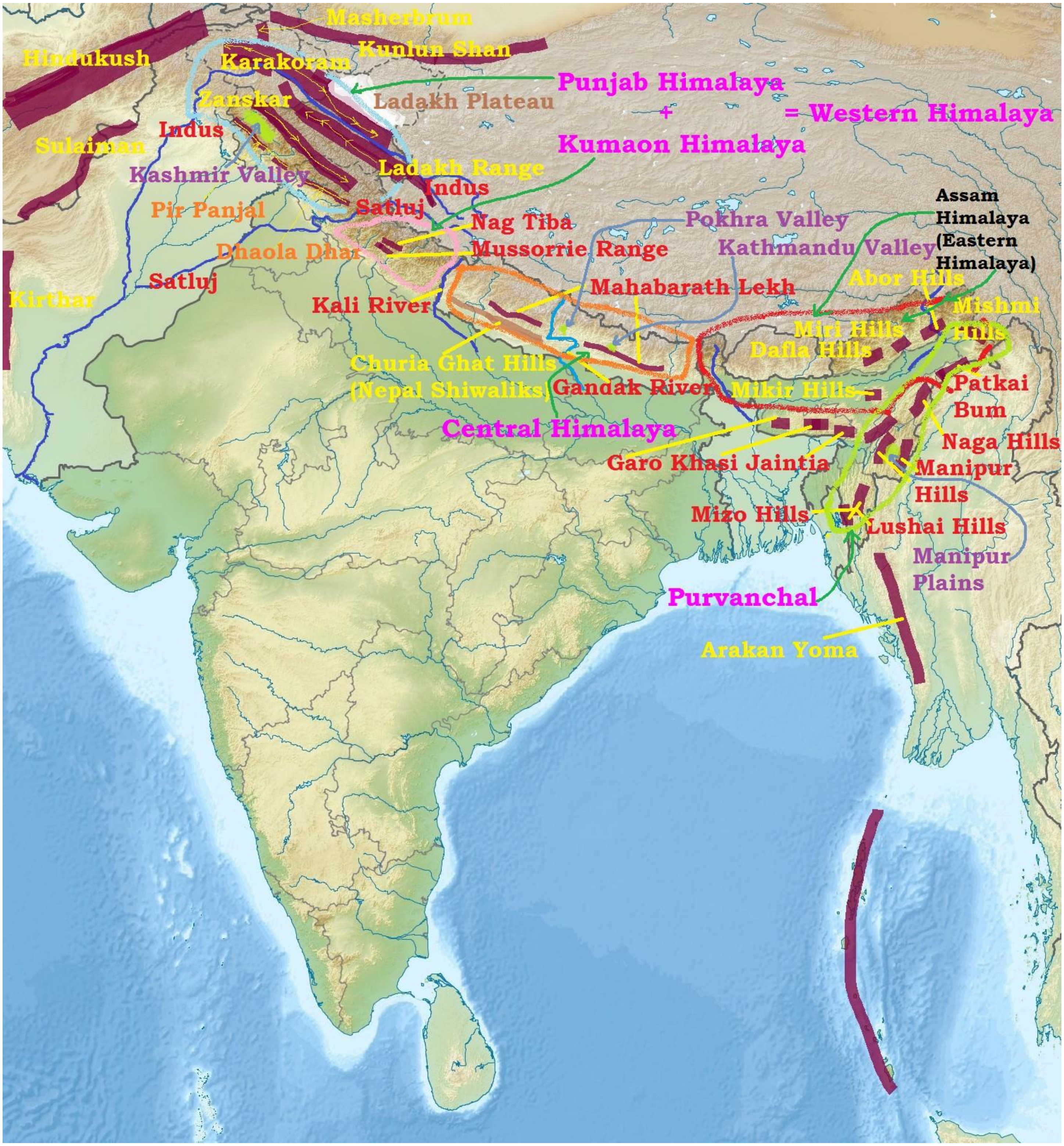
Purvanchal or Eastern Hills

- Eastern Hills or The Purvanchal are the southward extension of Himalayas running along the north-eastern edge of India.
- At the **Dihang gorge**, the Himalayas take a sudden southward bend and form a series of comparatively low hills which are collectively called as the Purvanchal.
- Purvanchal hills are convex to the west.
- They run along the India-Myanmar Border extending from Arunachal Pradesh in the north to Mizoram in the south.
- **Patkai Bum** hills are made up of strong sandstone; elevation varying from 2,000 m to 3,000 m; merges into Naga Hills where **Saramati (3,826 m)** is the highest peak.
- Patkai Bum and Naga Hills form the watershed between India and Myanmar.
- South of Naga Hills are the Manipur hills which are generally less than 2,500 metres in elevation.
- The Barail range separates Naga Hills from Manipur Hills.
- Further south the Barail Range swings to west into **Jaintia, Khasi and Garo hills** which are an eastward continuation of the **Indian peninsular block**. They are

separated from the main block by Ganga and Brahmaputra rivers.

- South of the Manipur Hills are the Mizo Hills (previously known as the **Lushai hills**) which have an elevation of less than 1,500 metres. The highest point is the **Blue Mountain (2,157 m)** in the south.





Syntaxial Bends of the Himalayas

- Himalayas extend in the east-west direction from the Indus gorge in the west to the Brahmaputra gorge in the east.
- Himalayan ranges take sharp southward bends at these gorges. These bends are called syntaxial bends of the Himalayas.
- The western syntaxial bend occurs near the **Naga Parbat (Karakoram range)** where the Indus river has cut a deep gorge.
- The eastern syntaxial bend occurs near the **Namche Barwa.**

In this post: Himalayas – Regional Divisions – Punjab Himalayas, Assam

Himalayas, Western Himalayas, Central Himalayas and Eastern Himalayas.

Himalayas – Regional Divisions

Punjab Himalayas

- Between the **Indus** and the **Satluj** rivers [560 km long].
- All the major rivers of Indus river system flow through Punjab Himalayas.
- A large portion of Punjab Himalayas is in Jammu and Kashmir and Himachal Pradesh. Hence they are also called the **Kashmir and Himachal Himalaya**.
- **Karakoram, Ladakh, Pir Panjal, Zaskar** and **Dhaola Dhar** are the major ranges in this section.
- The general elevation **falls westwards**.

Match List I with List II and select the correct answer: *[1997]*

List I (Climatic conditions)	List II (Reasons)
A. Madras is warmer than Calcutta	1. North-east monsoon
B. Snowfall in Himalayas	2. Altitude
C. Rainfall decreases from West Bengal to Punjab	3. Western depressions
D. Sutlej-Ganga plain gets some rain in winter	4. Distance from the sea
	5. Latitude

Codes:
(a) A – 1; B – 2; C – 4; D – 5
(b) A – 4; B – 5; C – 1; D – 3
(c) A – 5; B – 2; C – 4; D – 3
(d) A – 5; B – 1; C – 3; D – 4

Assam Himalayas

- Spreads over Sikkim, Assam and Arunachal Pradesh.
- Elevation here is much lesser than that of the Nepal Himalayas.
- The southern slopes are very steep but the northern slopes are gentle.
- **The Lesser Himalayas are very narrow and are very close to the Great Himalayas.**

Western Himalayas

- Between the **Indus in the west and the Kali river in the east (880 km).**
- Spread across three states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand.
- It encompasses three physiographic provinces namely **Kashmir Himalaya, Himachal Himalaya** and **Kumaon Himalaya (Uttarakhand Himalayas).**
- The Ladakh plateau and the Kashmir valley are two important areas of the Kashmir Himalayan region.
- In Himachal Himalayas, The Greater Himalaya is represented by the **Zaskar range**, lesser Himalaya by **Pir Panjal** and **Dhauladhar ranges** and the Outer Himalaya by the **Shiwalik range**.
- The southern slopes are rugged, steep and forested while the northern slopes are bare, gentle and show plains with lakes.
- The Kumaon Himalayas lie in Uttarakhand and extend from the **Satluj to the Kali river**.
- The Lesser Himalayas in Kumaon Himalaya is represented by the **Mussoorie and Nag Tiba ranges.**
- The Shiwalik in this region runs south of the Mussoori range between the Ganga and the Yamuna rivers.
- The flat valleys **between the Lesser Himalaya and the Shiwalik range are called 'doons'** or 'Duns' of which Dehra Dun is the most famous.

Central Himalayas

- 800 km between river Kali in the west and river Tista in the east.
- The Great Himalaya range attains maximum height in this portion.
- Some of the world famous peaks Mt. Everest, Kanchenjunga, Makalu, Annapurna, Gosainthan and Dhaulagiri are located here.
- The Lesser Himalaya is known as **Mahabharat Lekh** in this region.
- The range is crossed by rivers like Ghaghara, Gandak, Kosi, etc.

- In between the Great and the Lesser Himalayas, there are **Kathmandu and Pokhra** lacustrine **valleys** (previously, they were lakes).
- The Shiwalik range come very close to the lesser Himalaya towards the east and is almost non-existent beyond Narayani (Gandak).

Eastern Himalayas

- This part of the Himalayas lies between the Tista river in the west and the Brahmaputra river in the east and stretches for a distance of about 720 km.
- Also known as the **Assam Himalayas**, the Eastern Himalayas occupy mainly the areas of Arunachal Pradesh and Bhutan.
- The Assam Himalayas show a marked dominance of fluvial erosion due to **heavy rainfall.**
- The Himalayas take a sudden southward turn after the Dihang gorge and the hill ranges running in more or less north-south direction along India's border with Myanmar are collectively known as the Purvanchal.

These are known by various local names such as Patkai Bum, Naga hills, Kohima hills, Manipur hills, Mizo hills (previously known as the Lushai hills), Tripura hills and Barail range.

- The extension of the Purvanchal Himalaya continues southwards upto Andaman and Nicobar Islands through the Myanmar range (Arakan Yoma) and even upto the Indonesian archipelago.
- In the eastern section the Himalayas rise abruptly from the plains of Bengal and Oudh and suddenly attain great elevations within a short distance from the foot of the mountains. Thus the peaks of **Kanchenjunga** and **Everest** are only a few kilometres from the plains and are clearly visible from there.
- In contrast, the western Himalayas rise gradually from the plains through a series of ranges. Their peaks of perpetual snow are 150 to 200 km away from the plain areas.

In this post: Important Valleys in Himalayas – Karewas, Snow in Himalayas – Snowline, Glaciers in Himalayas and Significance of the Himalayas.

Important Valleys in Himalayas

The most important valleys in the Himalayan region are

- the **valley of Kashmir and the Karewas (),**
- **the Kangra and Kulu valley** in Himachal Pradesh;
- the **Dun valley (Doon valley, Dehradun valley)**; the Bhagirathi valley (near Gangotri) and the Mandakini valley (near Kedarnath) in Uttarakhand and
- the Kathmandu valley in Nepal.

Karewas

- Karewas are lacustrine deposits [deposits in lake] in the Valley of Kashmir and in Bhadarwah Valley of the Jammu Division.
- These are the flat topped mounds that border the Kashmir Valley on all sides.
- They are characterized with fossils of mammals and at places by peat.

Formation

- During the Pleistocene Period (1 million years ago), the entire Valley of Kashmir was under water.
- Subsequently, due to endogenetic forces, the Baramullah Gorge was created and the lake was drained through this gorge.
- The deposits left in the process are known as **karewas.**
- The thickness of karewas is about 1400 m.
- In fact, the karewas have been elevated, dissected and removed by subaerial denudation as well as by the Jhelum river giving them the present position.

Economic Significance

- The karewas are mainly devoted to the cultivation of saffron, almond, walnut, apple and orchards.
- The karewas, devoted to **saffron cultivation** are fetching good income to the growers.

Snow in Himalayas - Snowline

- In Eastern Himalayas and Kumaon Himalays the snowline is around 3,500 m above sea level whereas in western Himalays snowline is about 2,500 m above sea level.
- This difference in snowline is partly due to the **increase in latitude** from 28° N in Kanchenjunga to 36° N in the Karakoram.
- But the major factor is **precipitation.** Precipitation in western Himalayas is comparatively low and occurs mostly as snowfall where as in eastern Himalayas the precipitation is greater and occurs mostly in the form of rain.
- In the Great Himalayan ranges, the **snow line is at lower elevation on the southern slopes** than on the northern slopes because the **southern slopes are steeper** and receive more precipitation as compared to the northern slopes.

Glaciers in Himalayas

- There are about 15,000 glaciers in the Himalayas.
- Total area of Himalayas is about five lakh square kilometres (Area of India is nearly 32 lakh sq km). About 33,000 sq km area is covered by snow.
- The snow line (the lowest level of perpetual snow) varies in different parts of the Himalayas depending upon **latitude, amount of precipitation and local topography**.

Glaciers of the Karakoram Range

- Maximum development of glaciers occurs in the Karakoram range.
- Some of the largest glaciers outside the polar and sub-polar regions are found in this range. The southern side of this range has many gigantic glaciers.
- The **75 km long Siachen Glacier** in **Nubra valley** has the distinction of being the largest glacier outside the polar and the sub-polar regions.
- The second largest is the 74 km long **Fedchenko Glacier** (Pamirs)
- Third largest is the Hispar Glacier. It is 62 km long and occupies a tributary of the **Hunza River.**

Glaciers of the Pir Panjal Range

- The glaciers of the Pir Panjal Range are less numerous and smaller in size as compared to those of the Karakoram Range.
- The longest **Sonapani Glacier** in the **Chandra Valley** of **Lahul and Spiti region** is only 15 km long.

Glaciers of the Kumaon-Garhwal Region

- In the Kumaon-Garhwal region of the Himalayas, the largest is the 30 km long Gangotri Glacier which is the source of the holy Ganga.

Garhwal Region

- Lying in the Himalayas, it is bounded on the north by Tibet, on the east by Kumaon region, on the south by Uttar Pradesh state, and on the northwest by Himachal Pradesh state.

- It includes the districts of Chamoli, Dehradun, Haridwar, Pauri Garhwal, Rudraprayag, Tehri Garhwal, and Uttarkashi.

Glaciers of Central Nepal

- Zemu and the Kanchenjunga glaciers are the major ones.

Significance of the Himalayas

Influence on Indian Climate

- They **intercept the summer monsoons** coming from the Bay of Bengal and Arabian Sea causing precipitation in the entire Ganga Plains, North-Eastern Hills.
- They direct the monsoon winds **towards north-western India** (Punjab, Haryana etc.. But these regions receive most of the rainfall due to **Western Disturbances** coming from the Mediterranean regions).
- They **protect** northern-plains from the cold continental air masses of central Asia.
- The Himalayas influence the path of Sub-tropical Jet stream flowing in the region. They split the jet stream and this split jet stream plays an important role in bring monsoons to India.
- Had there been no Himalayas, the whole of India would have been a desert and its winters would have been very severe. [Mechanism of monsoons will be explained in detail later]

Defense

- The Himalayas are a natural defense barrier.
- But the Chinese aggression on India in 1962 has reduced the defense significance of the Himalayas.

Source of Rivers

- Rivers that feed nearly half a billion population of India originate in Himalayas. [we will study this in detail later in drainage system]
- All the rivers are perennial supplying water year round.

Fertile Soil

- The swift flowing rivers from Himalayas bring enormous amount of silt (alluvium) which constantly enrich the Ganaga and Bramhaputra plains.

Hydroelectricity

- Due to its natural topography and swift flowing perennial rivers, the Himalayan region offers several natural sites with great hydroelectric power generation potential.
- Many hydroelectric power plants have already been constructed.
- But all this comes at a great environmental costs.

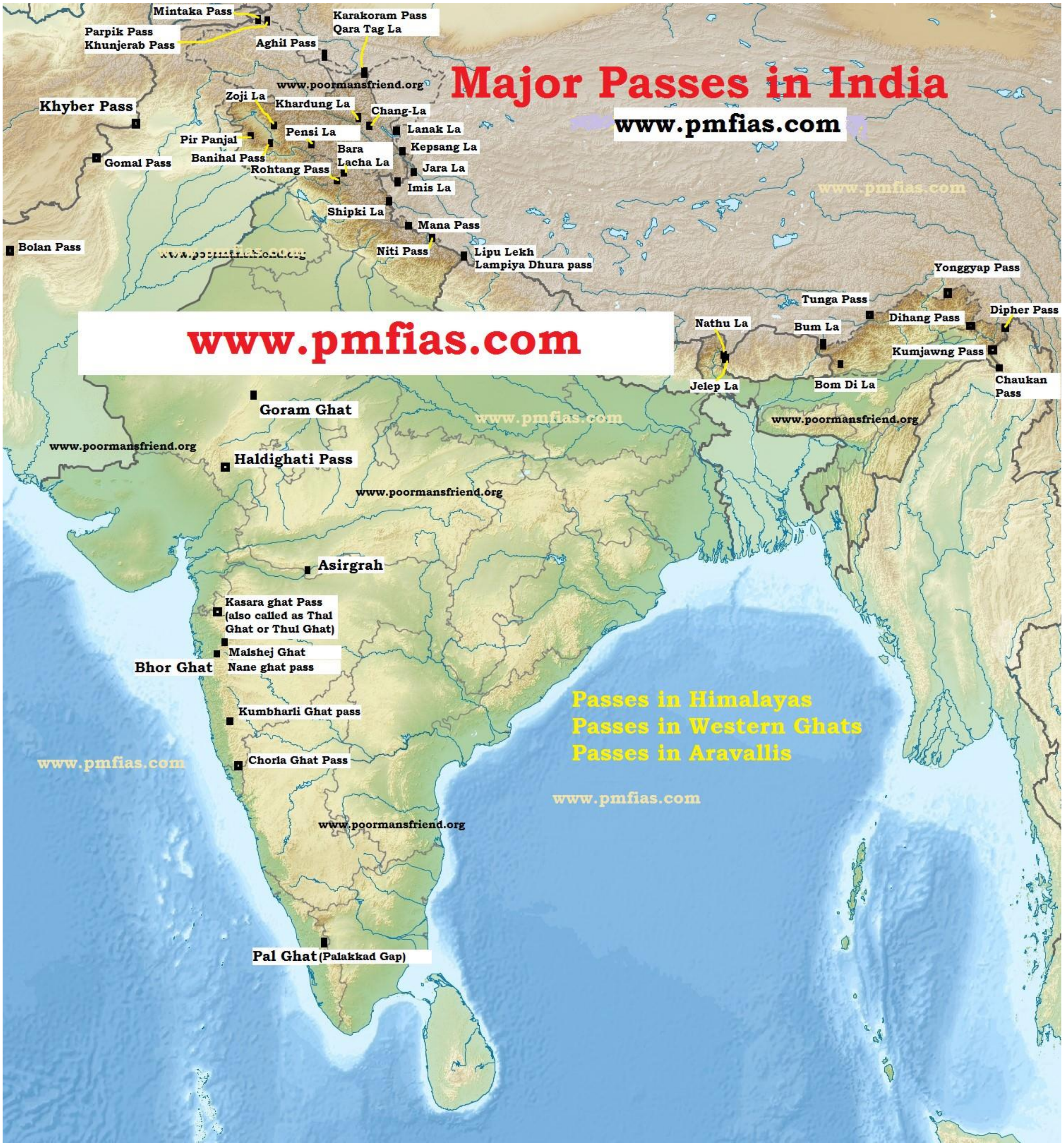
Forest Wealth

- The Himalayan host rich coniferous and evergreen forests. Lower levels have tropical evergreen forests and higher levels have Alpine vegetation (Coniferous).
- The Himalayan forests provide fuel wood and a large variety of timber for industries.
- Himalayan forests host wide variety of medicinal plants.
- Several patches are covered with grass offering rich pastures for grazing animals.

Agriculture

- Due to rugged and sloped terrain, the Himalayas are not potential agricultural sites.
- Some slopes are terraced for cultivation. Rice is the main crop on the terraced slopes. The other crops are wheat, maize, potatoes, etc.
- **Tea** is a unique crop which can be grown only on the **Shiwalik hill slopes** in the region.
- **Fruit cultivation** is a major occupation. A wide variety of fruits such as apples, pears, grapes, mulberry, walnut, cherries,

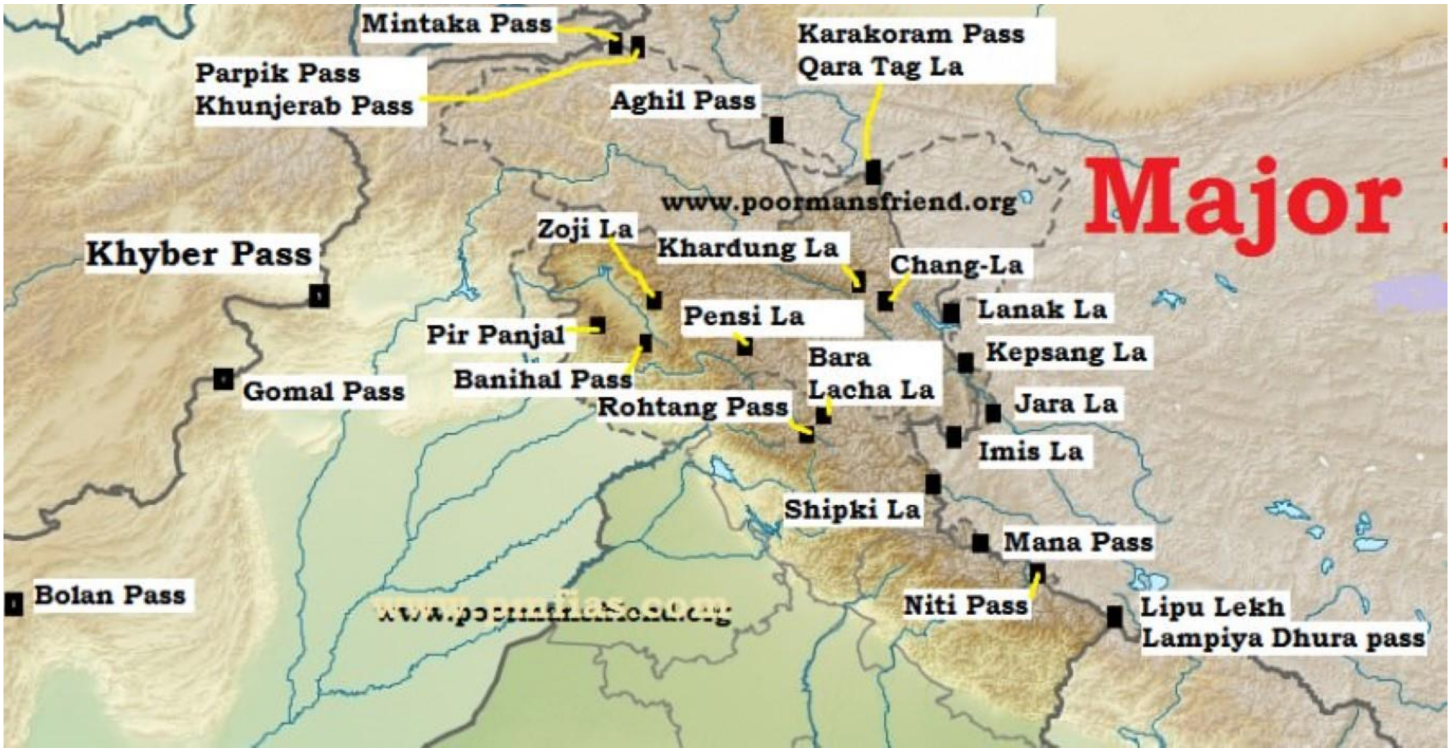
peaches, apricot, etc. are also grown in the Himalayan region.



Tourism

- Himalayan ranges have a large number of tourist spots.
- The hilly areas in the Himalayas are not affected by hot winds like loo. Hence they offer cool and comfortable climate.
- The increasing popularity of winter sports has increased the rush of tourists in winters.
- Srinagar, Dalhousie, Dharamshala, Chamba, Shimla, Kulu, Manali, Mussoorie, Nainital, Ranikhet, Almora, Darjeeling, Mirik, Gangtok, etc. are

important tourist centres in the Himalayas.

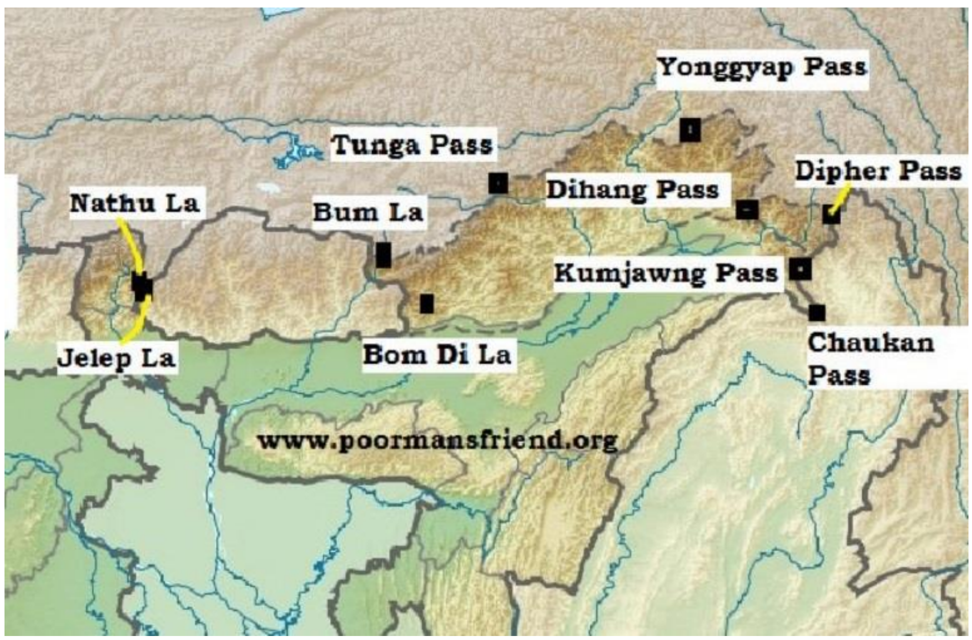


Cultural Tourism

- Himalayas host many Hindu and Buddist shrines.
- Kailas, Amarnath, Badrinath, Kedarnath, Vaishnu Devi, Jwalaji, Uttarkashi, Gangotri, Yamunotri, etc. are important places of pilgrimage.

Mineral Resources in Himalayas

- Geosynclinical deposits in tertiary rocks are regions of potential coal and oil reserves.
- Coal is found in Kashmir, Copper, lead, zinc, gold, silver, limestone, semi-precious and precious stones occur at some places in the Himalayas.
- But the exploitation of these resources require advanced technologies which are not yet available.
- Also, disturbing such a fragile environment leads to more pain than gain (present hydroelectric power projects have already proved this).



Major Passes in India and Indian Sub-continent

Main Passes of the Himalayas

- Most of the passes remain closed in winter (Nov – Apr) due to heavy snow fall.

Passes of the Western Himalayas

Jammu and Kashmir		
NAME	**SIGNIFICANCE (CONNECTS)**	**COMMENTS**
Mintaka Pass	Kashmir and China	**Trijunction of India-China and Afghanistan border**
Parpik Pass	Kashmir and China	East of Mintaka pass on the Indo-China border
Khunjerab Pass	Kashmir and China	Indo-China border
Aghil Pass	Ladakh region of India with the Xinjiang (Sinkiang) Province of China	5000 m above sea level. north of K2 Peak (the highest peak in India and the second highest peak in the world)
Banihal Pass	Jammu and Srinigar	2832 m across the Pir-Panjal Range remains snow covered during winter season
	The road from Jammu to Srinagar transversed Banihal Pass until 1956 when **Jawahar Tunnel** was constructed under the pass. The road now passes through the tunnel and the Banihal Pass is no longer used for road transport. Another 11 km long tunnel provides railway link between Banihal and Kazigund. It was thrown open to railway transport in July, 2013	
Chang-La	Ladakh with Tibet	altitude of 5360 m This has a temple dedicated to Chang-La Baba after whom the temple has been named
Khardung La	near Leh in the Ladakh range	5602 m **The world's highest motorable road passes through this pass** remains closed in winter due to heavy snowfall
Lanak La	India and China (Akasai-Chin area of Jammu and Kashmir)	this pass provides passage between Ladak and Lhasa. A road to connect Xinjiang Province with Tibet has been constructed by the Chinese
Pir-Panjal pass	across the Pir Panjal range	**provides the shortest and the easiest metal road between Jammu and Kashmir Valley. But this route had to be closed down as a result of partition of the subcontinent**
Qara Tag La	Indo-China borer across the Karakoram Range	located at an elevation of over six thousand metres
Imis La	Ladakh region of India and Tibet in China	
Pensi La	vital link between the Kashmir Valley and Kargil	remains closed to traffic from November to mid-May due to heavy snowfall
Zoji La	important road link between Srinagar on one side and Kargil and Leh on the other side	The road passing through this pass has been designated at the **National Highway (NH-1D)** **Border Road Organisation (BRO)** is responsible for maintaining the road and cleaning it off snow during winter. In spite of all these efforts, the road through this pass remains closed from

		December to mid-May
Himachal Pradesh		
Bara Lacha La	Himachal Pradesh and Jammu and Kashmir	Elevation: 4,890 m National highway connecting Mandi in Himachal Pradesh with Leh in Jammu and Kashmir passes through this pass. Being situated at high altitude, it remains snow covered in winter and is not used as a transport route.
Debsa Pass	link between Kullu and Spiti districts	elevation of 5270 m above sea level It offers a much easier and shorter alternative route to traditional Pin-Parbati Pass route between Kullu and Spiti
Rohtang Pass	road link between Kullu, Lahul and Spiti Valleys	Elevation: 3979 m Border Road Organisation (BRO) is responsible for constructing and maintaining roads in this area. **Rohtang pass is a great tourist attraction and traffic jams are very common** because this route is widely used by military, public and private vehicles.
Shipki La	Himachal Pradesh and Tibet	Elevation: 6000 m Remains closed in winter season (Nov - Apr)
Uttarakhand		
Lipu Lekh	trijunction of Uttarakhand (India), Tibet (China) and Nepal borders	**This pass is used by pilgrims to Kailash-Mansarowar.**
Mana Pass	Uttarakhand with Tibet	elevation of 5610 Situated a little north of the holy place of Badhrinath Remains closed in winter season (Nov - Apr)
Mangsha Dhura	Uttarakhand with Tibet	**It is used by pilgrims going to Kailash-Mansarowar**
Niti Pass	Uttarakhand with Tibet	Remains closed in winter season (Nov - Apr)
Muling La	Uttarakhand and Tibet	**situated in the north of Gangotri** at an elevation of 5669 m in the Great Himalayas
Passes of the Eastern Himalayas		
Sikkim		
Nathu La	Sikkim with Tibet	altitude of 4310 m it forms part of an **offshoot of the ancient Silk Route** an important trade route between India and China It was closed after the Chinese aggression on India in 1962 but was reopened in 2006 as the governments of the two countries decided to enhance their trade through land routes
Jelep La	Sikkim-Bhutan border	altitude of 4538 m

		passes through **Chumbi Valley** important link between Sikkim and Lhasa
Arunachal Pradesh		
Bom Di La	Arunachal Pradesh with Bhutan	altitude of 4331 m Situated at an altitude of 4331 m near the western boundary of Bhutan in the Greater Himalayas, this pass connects Arunachal Pradesh with Lhasa
Dihang Pass	Arunachal Pradesh and Myanmar.	elevation of more than 4000 m it provides passage
Yonggyap Pass	Arunachal Pradesh with Tibet	
Dipher Pass	trijunction of India, China and Myanmar	easy access between Arunachal Pradesh and Mandalay in Myanmar. It is an important land trade route between India and Myanmar and remains open throughout the year.
Kumjawng Pass	Arunachal Pradesh with Myanmar	
Hpungan Pass	Arunachal Pradesh with Myanmar	
Chankan Pass	Arunachal Pradesh with Myanmar	

In this post: Formation of Indo – Gangetic – Brahmaputra Plain, Features of Indo – Gangetic – Brahmaputra Plain, Geomorphological features of Indo – Gangetic – Brahmaputra Plain: Bhabar, Terai, Bhangar, Khadar and Reh or Kollar.

Formation of Indo – Gangetic – Brahmaputra Plain

- The formation of Indo-Gangetic plain is closely related to the formation of Himalayas.

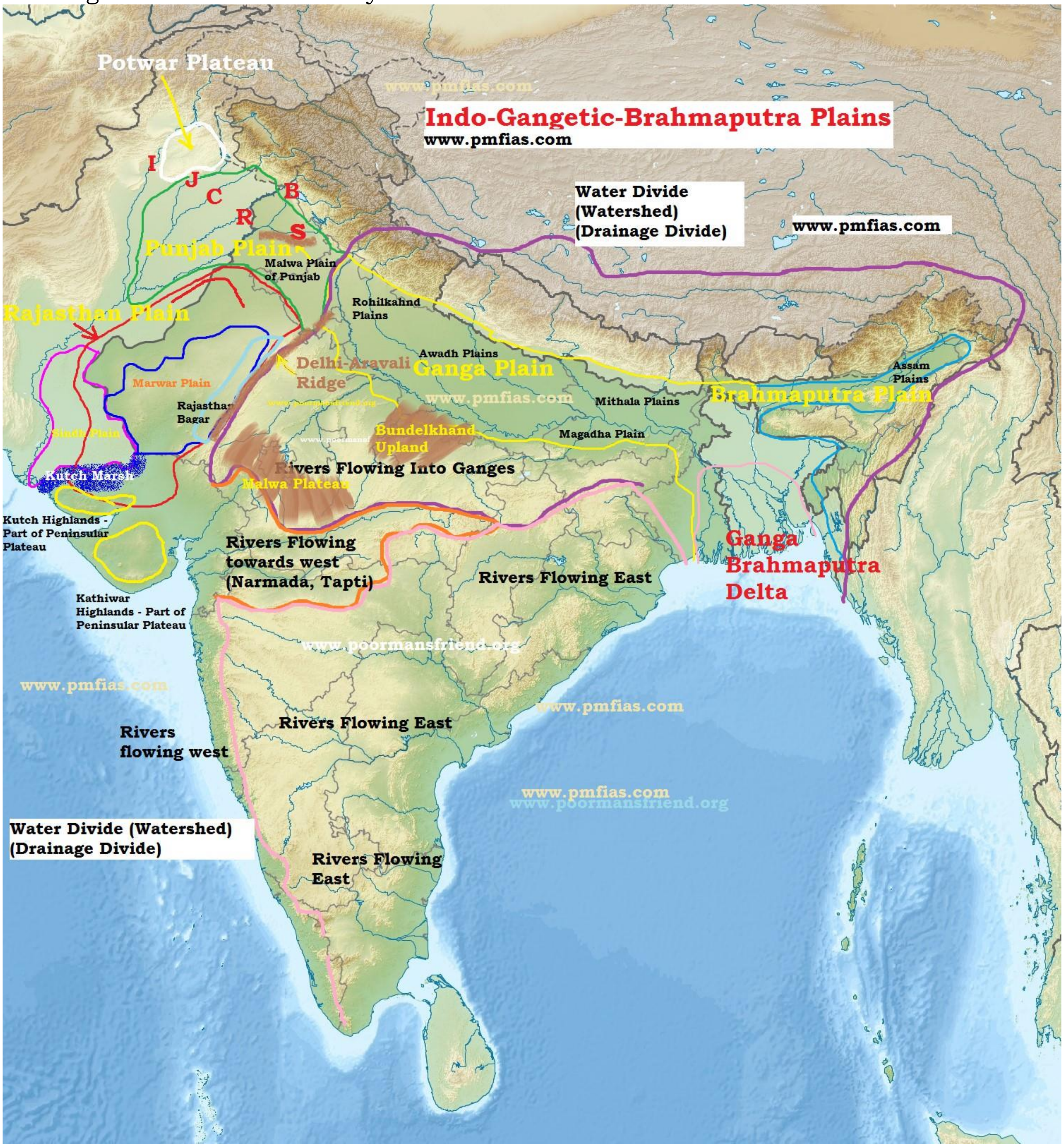
Formation of Indo – Gangetic – Brahmaputra trough

- The rivers which were previously flowing into **Tethys sea** (Before Indian Plate collided with Eurasian Plate – continental drift, plate tectonics) deposited huge amount of sediments in the **Tethys Geosyncline. [Geosyncline – a huge depression]**
- Himalayas are formed out of these sediments which were uplifted, folded and compressed due to northern movement of Indian Plate.
- Northern movement of Indian Plate also **created a trough** to the south of Himalayas.

Depositional Activity

- During the initial stages of upliftment of sediments, the already existing rivers changed their course several times and they were **rejuvenated** each time (perpetual youth stage of rivers {Fluvial Landforms}).
- The rejuvenation is associated with intense **headward and vertical downcutting** of the soft strata overlying the harder rock stratum.
- Headward erosion and vertical erosion of the river valley in the initial stages, lateral erosion in later stages contributed huge amount of conglomerates (detritus)(rock debris, silt, clay etc.) which were carried downslope.

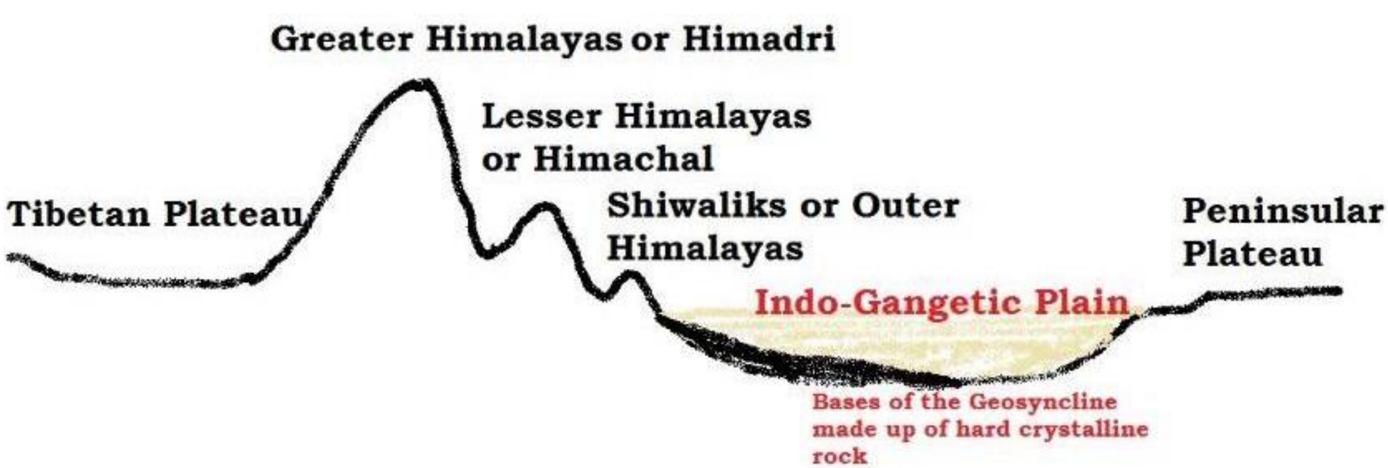
- [**Head ward erosion** == Erosion at the origin of a stream channel, which causes the origin to move back away from the direction of the stream flow, and so causes the stream channel to lengthen]



- These conglomerates were deposited in the **depression (Indo-Gangetic Trough or Indo-Gangetic syncline) (the base of the geosyncline is a hard crystalline rock)** between peninsular India and the convergent boundary (the region of present day Himalayas).

New rivers and more alluvium

- The raising of Himalayas and subsequent formation of glaciers gave rise to many new rivers. These rivers along with glacial erosion {Glacial Landforms}, supplied more alluvium which intensified the filling of the depression.
- With the accumulation of more and more sediments (conglomerates), the Tethys sea started receding.
- With passage of the time, the depression was completely filled with alluvium, gravel, rock debris (conglomerates) and the Tethys completely disappeared leaving behind a monotonous aggradational plain.
- [**monotonous** == featureless topography; **aggradational plain** == plain formed due to depositional activity. Indo-Gangetic plain is a monotonous aggradational plain formed due to fluvial depositions].
- Upper peninsular rivers have also contributed to the formation of plains, but to a very small extent.
- During the recent times (since few million years), depositional work of three major river systems viz., the Indus, the Ganga and the Brahmaputra have become predominant.
- Hence this arcuate (curved) plain is also known as **Indo-Gangetic-Brahmaputra Plain**.



Features of Indo – Gangetic – Brahmaputra Plain

- Indo-Gangetic-Brahmaputra Plain is the **largest alluvial tract of the world**.

- It stretches for about **3,200 km** from the mouth of the Indus to the mouth of the Ganga. Indian sector of the plain accounts for **2,400 km.**
- The northern boundary is well marked by the **Shiwaliks** and the southern boundary is a wavy irregular line along the northern edge of the Peninsular India.
- The western boarder is marked by **Sulaiman and Kirthar ranges**. On the eastern side, the plains are bordered by Purvanchal hills.
- The width of the plain varies from region to region. It is widest in the west where it stretches for about 500 km. Its width decreases in the east.
- The thickness of the alluvium deposits also vary from place to place. The maximum depth of the alluvium up to the basement rocks is about 6,100 m (not uniform and varies greatly from place to place).
- The cones or alluvial fans of Kosi in the north and those of Son in the south exhibit greater alluvial thickness while the intra-cone areas have relatively shallower deposits.
- Extreme horizontality of this monotonous plain is its chief characteristic.
- Its average elevation is about 200 m above mean sea level, highest elevation being 291 m above mean sea level near **Ambala** (**This elevation forms the drainage divide or watershed between Indus system and Ganga system**).
- Its average gradient from Saharanpur to Kolkata is only 20 cm per km and it decreases to 15 cm per km from Varanasi to the Ganga delta.

Geomorphological features of Indo – Gangetic – Brahmaputra Plain

The Bhabar

- It is a **narrow, porous, northern most** stretch of Indo-Gangetic plain.
- It is about 8-16 km wide running in east-west direction **along the foothills** (alluvial fans) of the Shiwaliks.
- They show a remarkable continuity from the **Indus to the Tista**.
- Rivers descending from the Himalayas deposit their load along the foothills in the form of **alluvial fans**.
- These alluvial fans have merged together to build up the **bhabar belt.**
- The **porosity** of bhabar is the most unique feature.
- The porosity is due to deposition of huge number of **pebbles and rock debris** across the alluvial fans.
- The streams disappear once they reach the bhabar region because of this porosity.
- Therefore, the area is marked by **dry river courses** except in the rainy season.
- The Bhabar belt is comparatively **narrow in the east** and extensive in the western and north-western hilly region.

The area is not suitable for agriculture and only big trees with large roots thrive in this belt.

The Terai

- Terai is an **ill-drained, damp (marshy) and thickly forested narrow tract** to the south of Bhabar running parallel to it.
- The Terai is about15-30 km wide.
- The underground streams of the Bhabar belt **re-emerge** in this belt.

This thickly forested region provides shelter to a variety of wild life. [Jim Corbett National Park in Uttarakhand and Kaziranga National Park in Assam lie in terai region]

- The Terai is more marked in the eastern part than in the west because the eastern parts receive comparatively higher amount of rainfall.

- Most of the Terai land, especially in Punjab, Uttar Pradesh and Uttarakhand, has been turned into agricultural land which gives good crops of **sugarcane, rice and wheat.**

The Bhangar

- The Bhangar is the **older alluvium** along the river beds **forming terraces higher than the flood plain.**
- The terraces are often impregnated with calcareous concretions known as **'KANKAR'.**
- **'The Barind plains'** in the deltaic region of Bengal and the **'bhur formations'** in the middle Ganga and Yamuna doab are regional variations of Bhangar.

[**Bhur** denotes an elevated piece of land situated along the banks of the Ganga river especially in the upper Ganga-Yamuna Doab. This has been formed due to accumulation of wind-blown sands during the hot dry months of the year]

- Bhangar contains fossils of animals like rhinoceros, hippopotamus, elephants, etc.

The Khadar

- The Khadar is composed of **newer alluvium** and forms the **flood plains** along the river banks.
- A **new layer of alluvium is deposited** by river flood almost every year.
- This makes them the **most fertile soils of Ganges**.

Reh or Kollar

- Reh or Kollar comprises **saline efflorescences** of drier areas in Haryana.
- Reh areas have spread in recent times with increase in irrigation (capillary action brings salts to the surface).

Regional Divisions of the Great Plains

1. **Sindh Plain**
2. **Rajasthan Plain.**
3. **Punjab Plain.**
4. **Ganga Plain.**
5. **Brahmaputra Plain.**
6. **Ganga – Brahmaputra Delta**

Sindh Plain [Pakistan]

- Mainly formed of **Bhangar Plains**.
- Dhors: Long narrow depressions which are the remnants of the course of former rivers.
- Dhand: Alkaline lakes on some dhors.

Rajasthan Plain

- Occupied by Thar or the Great Indian Desert.
- This plain is an **undulating plain [wave like]** whose average elevation is about 325 m above mean sea level.
- The desert region is called **Marusthali** and forms a greater part of the **Marwar plain**.
- It has a few outcrops of gneisses, schists and granites which proves that geologically it is a part of the Peninsular Plateau. It is only at the surface that it looks like an aggradational plain.
- In general, the eastern part of the Marusthali is rocky while its western part is covered by shifting sand dunes locally known as **dhrian.**
- The eastern part of the Thar Desert up to the Aravali Range is a semi-arid plain known as **Rajasthan Bagar**.
- It is drained by a number of **short seasonal streams** originating from the Aravali and supports agriculture in some patches of fertile tracts**.**
- Luni is an important seasonal stream which flows into Rann of Kuchchh. The tract north of the Luni is known as **thali** or **sandy plain.**

Saline Lakes

- North of the Luni, there is inland drainage having several saline lakes. They are a source of common salt and many other salts.

- **Sambhar**, Didwana, Degana, Kuchaman, etc. are some of the important lakes. The largest is the Sambhar lake near Jaipur.

Punjab Plain

- This plain is formed by five important rivers of Indus system.
- The plain is primarily made up of 'doabs' —the land between two rivers.
- The depositional process by the rivers has united these doabs giving an homogenous appearance.
- Punjab literally means "(The Land of) Five Waters" referring to the following rivers: the **Jhelum, Chenab, Ravi, Sutlej, and Beas**.
- The total area of this plain is about 1.75 lakh sq km.
- The average elevation of the plain is about 250 m above mean sea level.
- The eastern boundary of Punjab Haryana plain is marked by subsurface **Delhi-Aravali ridge.**
- The northern part of this plain [Shiwalik hills] has been intensively eroded by numerous streams called **Chos**. This has led to enormous gullying [Arid Landforms].
- To the south of the Satluj river there is **Malwa plain** of Punjab.
- The area between the Ghaggar and the Yamuna rivers lies in Haryana and often termed as '**Haryana Tract**'. It acts as water-divide between the Yamuna and the Satluj rivers.
- **The only river between the Yamuna and the Satluj is the Ghaggar which is considered to be the present day Successor of the legendary Saraswati River**

Ganga Plain

- This is the largest unit of the Great Plain of India stretching from Delhi to Kolkata (about 3.75 lakh sq km).
- The Ganga along with its large number of tributaries originating in the Himalayans have brought large quantities of alluvium from the mountains and deposited it here to build this extensive plain.
- The peninsular rivers such as Chambal, Betwa, Ken, Son, etc. joining the Ganga river system have also contributed to the formation of this plain.
- The general slope of the entire plain is to the east and south east.
- Rivers flow sluggishly in the lower sections of Ganges as a result of which the area is marked by local prominences such as **levees, bluffs, oxbow lakes, marshes, ravines**, etc. {Fluvial Landforms, Arid Landfroms}
- Almost all the rivers keep on shifting their courses making this area prone to frequent floods. The Kosi river is very notorious in this respect. It has long been called the **'Sorrow of Bihar'**.

Regional divisions of Ganga plains

- **Rohilkhand plains**
- **Avadh Plains**
- **Mithila Plain**
- **Magadh Plain.**

Ganga-Brahmaputra Delta

- This is the **largest delta** in the world.
- The Ganga river divides itself into several channels in the delta area. The slope of the land here is a mere 2 cm per km. Two thirds of the area is below 30 m above mean sea level. [Highly vulnerable to sea level changes]
- The seaward face of the delta is studded with a large number of estuaries, mud flats, mangrove swamps, sandbanks, islands and forelands.
- Large part of the coastal delta is covered **tidal forests**. These are called the **Sunderbans** because of the predominance of Sundri tree here.

Brahmaputra Plain

- This is also known as the Brahmaputra valley or **Assam Valley** or **Assam Plain** as most of the Brahmaputra valley is situated in Assam.
- Its western boundary is formed by the Indo-Bangladesh border as well as the

boundary of the lower Ganga Plain. Its eastern boundary is formed by **Purvanchal hills.**

- It is an **aggradational plain** built up by the depositional work of the Brahmaputra and its tributaries.
- The innumerable tributaries of the Brahmaputra river coming from the north form a number of alluvial fans. Consequently, the tributaries branch out in many channels giving birth to river meandering leading to formation of bill and ox-bow lakes.
- There are large marshy tracts in this area. The alluvial fans formed by the coarse alluvial debris have led to the formation of terai or semi-terai conditions.

Significance of the Plain

- This one fourth of the land of the country hosts half of the Indian population.
- Fertile alluvial soils, flat surface, slow moving perennial rivers and favorable climate facilitate intense agricultural activity.
- The extensive use of irrigation has made Punjab, Haryana and western part of Uttar Pradesh the granary of India (**Prairies** are called the granaries of the world).
- The entire plain except the Thar Desert, has a close network of roads and railways which has led to large scale industrialization and urbanization.
- Cultural tourism: There are many religious places along the banks of the sacred rivers like the Ganga and the Yamuna which are very dear to Hindus. Here flourished the religions of Budha and Mahavira and the movements of Bhakti and Sufism.

In this post: Peninsular Plateau – Features of the Peninsular Plateau – Marwar Plateau or Mewar Plateau, Central Highland, Bundelkhand Upland, Malwa Plateau, Baghelkhand, Chotanagpur Plateau, Meghalaya Plateau, Deccan Plateau, Maharashtra Plateau, Karnataka Plateau, Telangana plateau and Chhattisgarh Plain.

Peninsular Plateau

Features of the Peninsular Plateau

- Roughly triangular in shape with its base coinciding with the southern edge of the great plain of North India. Apex of the triangular plateau is at Kanniyakumari.
- It covers a total area of about **16 lakh sq km** (India as a whole is 32 lakh sq km).
- The average height of the plateau is **600-900 m** above sea level (varies from region to region).
- Most of the peninsular rivers flow west to east indicating it's general slope.
- Narmada-Tapti are the exceptions which flow from east to west in a **rift (rift is caused by divergent boundary (Go back to Interaction of plates).**
- The Peninsular Plateau is a one of the oldest landforms of earth.
- It is a highly stable block composed mostly of the **Archaean gneisses and schists** {Rock System}.
- It has been a stable shield which has gone through little structural changes since its formation.
- Since few hundred million years, Peninsular block has been a land area and has never been submerged beneath the sea except in a few places.
- Peninsular Plateau is an aggregation of several smaller plateaus, hill ranges interspersed with river basins and valleys.

Minor Plateaus in the Peninsular Plateau

Marwar Plateau or Mewar Plateau

- It is the plateau of eastern Rajasthan. [**Marwar plain** is to the west of Aravalis whereas Marwar plateau is to the east].
- The average elevation is 250-500 m above sea level and it slopes down eastwards.
- It is made up of sandstone, shales and limestones of the Vindhayan period.

- The **Banas river**, along with its tributaries **[Berach river, Khari rivers]** originate in the Aravali Range and flow towards northwest into **Chambal river**. The erosional activity of these rives make the plateau top appear like a **rolling plain**.

[Rolling Plain: 'Rolling plains' are not completely flat: there are slight rises and fall in the land form. Ex: Prairies of USA]

Central Highland

- Also called the **Madhya Bharat Pathar** or **Madhya Bharat Plateau**.
- It is to the east of the Marwar or Mewar Upland.

- Most of plateau comprises the basin of the **Chambal river** which flows in a **rift valley.**
- The **Kali Sindh**, flowing from **Rana Prataph Sagar**, The **Banas** flowing through Mewar plateau and The **Parwan** and the **Parbati** flowing from Madhya Pradesh are its main tributaries.
- It is a rolling plateau with rounded hills composed of sandstone. Thick forests grow here.
- To the north are the **ravines or badlands** of the Chambal river [They are typical to Chambal river basin]{ **Arid landforms**}.

Bundelkhand Upland

- Yamuna river to the north, Madhya Bharat Pathar to the west, Vindhyan Scarplands to the east and south-east and Malwa Plateau to the south.
- It is the old dissected (divided by a number of deep valleys) upland of the 'Bundelkhand gneiss' comprising of **granite** and **gneiss**.
- Spreads over five districts of Uttar Pradesh and four districts of Madhya Pradesh.
- Average elevation of 300-600 m above sea level, this area slopes down from the Vindhyan Scarp toward the Yamuna River.
- The area is marked by a chain of hillocks (small hill) made of granite and sandstone.
- The erosional work of the rivers flowing here have converted it into an undulating (wave like surface) area and rendered it **unfit for cultivation**.
- The region is characterized by senile (characteristic of or caused by old age) topography.
- Streams like **Betwa, Dhasan** and **Ken** flow through the plateau.

Malwa Plateau

- The Malwa Plateau roughly forms a triangle based on the Vindhyan Hills, bounded by the Aravali Range in the west and Madhya Bharat Pathar to the north and Bundelkhand to the east.
- This plateau has two systems of drainage; one towards the Arabian sea (The **Narmada**, the **Tapi** and the **Mahi**), and the other towards the Bay of Bengal (Chambal and Betwa, joining the Yamuna).
- In the north it is drained by the Chambal and many of its right bank tributaries like the Kali, the Sindh and the Parbati. It also includes the upper courses of the Sindh, the Ken and the Betwa.
- It is composed of extensive **lava flow and is covered with black soils**.
- The general slope is towards the north [decreases from 600 m in the south to less than 500 m in the north]
- This is a rolling plateau dissected by rivers. In the north, the plateau is marked by the **Chambal ravines**.

Baghelkhand

- North of the **Maikal Range** is the Baghelkhand.
- Made of limestones and sandstones on the west and granite in the east.
- It is bounded by the Son river on the north.
- The central part of the plateau acts as a water divide between the **Son** drainage system in the north and the **Mahanadi** river system in the south.
- The region is uneven with general elevation varying from 150 m to 1,200 m.
- The **Bhanrer** and **Kaimur** are located close to the trough-axis.
- The general horizontality of the strata shows that this area has not undergone any major disturbance.

Chotanagpur Plateau

- Chotanagpur plateau represents the north-eastern projection of the Indian Peninsula.
- Mostly in Jharkhand, northern part of Chhatisgarh and Purulia district of West Bengal.
- The **Son river** flows in the north-west of the plateau and joins the Ganga.
- The average elevation of the plateau is 700 m above sea level.
- This plateau is composed mainly of **Gondwana rocks.**

- The plateau is drained by numerous rivers and streams in different directions and presents a **radial drainage pattern.** {Drainage Pattern}
- Rivers like the **Damodar**, the **Subarnrekaha**, the **North Koel**, the **South Koel** and the **Barkar** have developed extensive drainage basins.
- The Damodar river flows through the middle of this region in a rift valley from west to east. Here are found the **Gondwana coal fields** which provide bulk of coal in India.
- North of the Damodar river is the **Hazaribagh plateau** with an average elevation of 600 m above mean sea level. This plateau has isolated hills. It looks like a peneplain due to large scale erosion.
- The **Ranchi Plateau** to the south of the Damodar Valley rises to about 600 m above mean sea level. Most of the surface is rolling where the city of Ranchi (661 m) is located.
- At places it is interruped by **monadnocks** (an isolated hill or ridge of erosion-resistant rock rising above a peneplain. Ex: Ayers Rock in Australia) and conical hills.
- The **Rajmahal Hills** forming the north eastern edge of the Chotanagpur Plateau are mostly made of basalt and are covered by lava flows {Basaltic Lava}.
- They run in north-south direction and rise to average elevation of 400 m (highest mount is 567 m). These hills have been dissected into separate plateaus.

Meghalaya Plateau

- The peninsular plateau extends further east beyond the Rajmahal hills to from **Meghalaya** or the **Shillong plateau**.
- **Garo-Rajmahal Gap** separates this plateau from the main block.
- This gap was formed by **down-faulting** (normal fault: a block of earth slides downwards). It was later filled by sediments deposited by the Ganga and Brahmaputa.
- The plateau is formed by Archaean quartzites, shales and schists.
- The plateau slopes down to Brahmaputra valley in the north and the Surma and Meghna valleys in the south.
- Its western boundary more or less coincides with the Bangladesh border.
- The western, central and the eastern parts of the plateau are known as the **Garo Hills** (900 m), the **Khasi-Jaintia Hills** (1,500 m) and the **Mikir Hills** (700 m).
- **Shillong (1,961 m) is the highest point of the plateau.**

Deccan Plateau

- It covers an area of about **five lakh sq km.**
- It is triangular in shape and is bounded by the **Satpura** and the **Vindhya** in the north-west, the **Mahadev** and the **Maikal** in the north, the **Western Ghats** in the west and the **Eastern Ghats** in the east.
- Its average elevation is 600 m.
- It rises to 1000 m in the south but dips to 500 m in the north.
- Its general slope is from west to east which is indicated by the flow of its major rivers.
- Rivers have further subdivided this plateau into a number of smaller plateaus.

Maharashtra Plateau

- The Maharashtra Plateau lies in Maharashtra.
- It forms the northern part of the Deccan Plateau.
- Much of the region is underlain by **basaltic rocks** of lava origin **[Most of the Deccan Traps lies in this region].**
- The area looks like a rolling plain due to weathering.
- The horizontal lava sheets have led to the formation of typical Deccan Trap topography [step like].
- The broad and shallow valleys of the Godavari, the Bhima and the Krishna are flanked [bordered on the opposite sides] by flat-topped steep sided hills and ridges.
- The entire area is covered by black cotton soil known as **regur.**

Karnataka Plateau

- The Karnataka Plateau is also known as the **Mysore plateau**.
- Lies to the south of the Maharashtra plateau.
- The area looks like a rolling plateau with an average elevation of 600-900 m.
- It is highly dissected by numerous rivers rising from the Western Ghats.
- The general trend of the hills is either parallel to the Western Ghats or across it.
- The **highest peak (1913 m) is at Mulangiri in Baba Budan Hills in Chikmaglur district.**
- The plateau is divided into two parts called **Malnad** and **Maidan.**
- The Malnad in Kannada means hill country. It is dissected into deep valleys covered with dense forests.
- The Maidan on the other hand is formed of rolling plain with low granite hills.
- The plateau tapers between the Western Ghats and the Eastern Ghats in the south and merges with the **Niligiri hills** there.

Telangana plateau

- The Telangana plateau consists of Archaean gneisses.
- It's average elevation is 500-600 m.
- The southern part is higher than its northern counterpart.
- The region is drained by three river systems, the Godavari, the Krishna and the Penneru.
- The entire plateau is divided into Ghats and the Peneplains (a vast featureless, undulating plain which the last stage of deposition process).

Chhattisgarh Plain

- The Chhattisgarh **plain** is the only plain worth the name in the Peninsular plateau.
- It is a saucer shaped depression drained by the upper Mahanadi.
- The whole basin lies between the **Maikala Range** and the **Odisha hills**.
- The region was once ruled by **Haithaivanshi Rajputs** from whose thirty six forts (Chhattisgarh) it derives its name.
- The basin is laid with nearly horizontal beds of limestone and shales.
- The general elevation of the plain ranges from 250 m in the east to 330 m in the west.

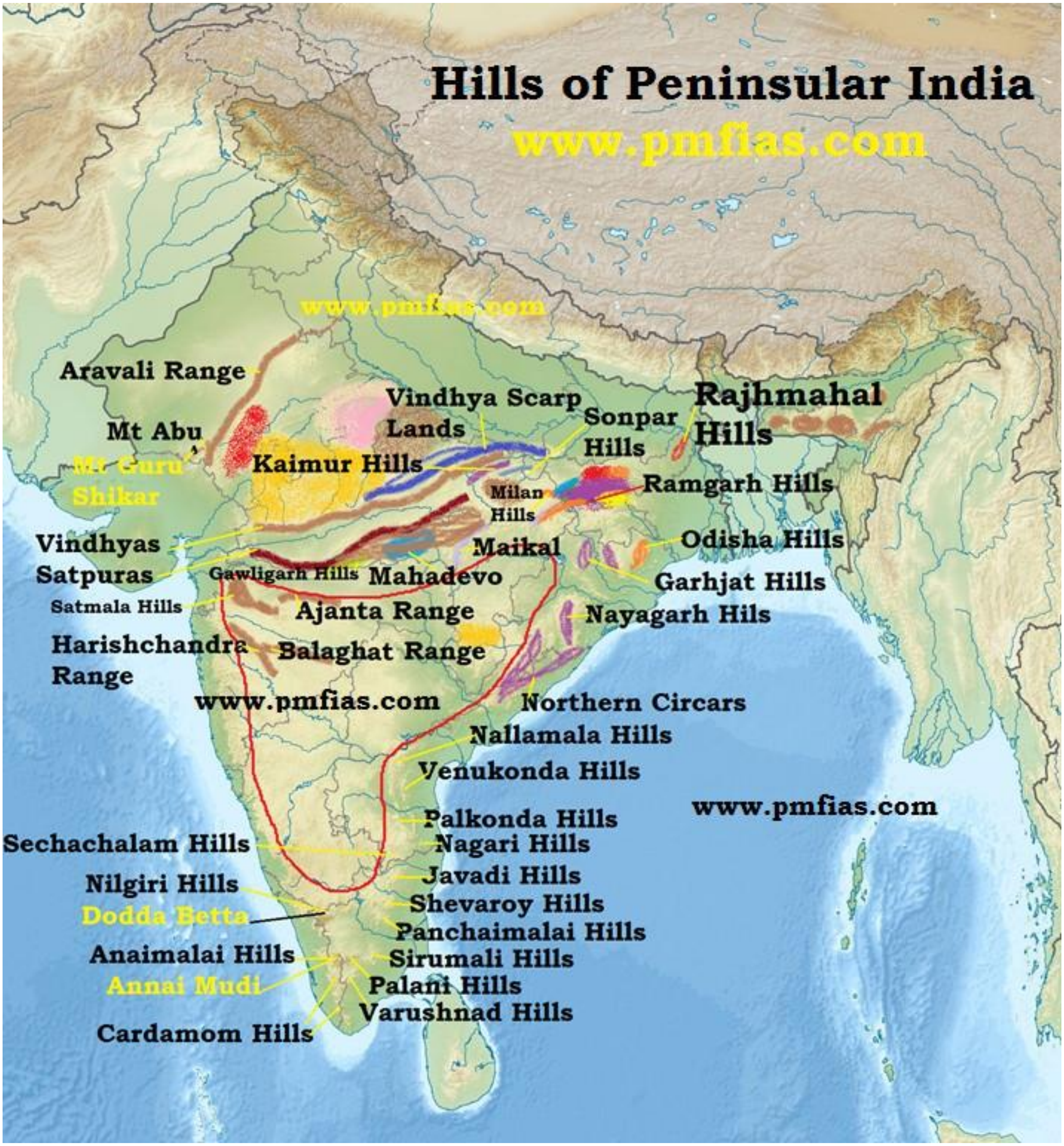
In this post: Hills of Peninsular India - Aravalis, Vindhyas, Satpuras, Western Ghats, Sahyadris, Eastern Ghats. Hill Ranges of the Peninsular Plateau - Aravali Range, Vindhyan Range, Satpura Range, Western Ghats [Sahyadris] and Eastern Ghats.

Hill Ranges of the Peninsular Plateau

- Most of the hills in the peninsular region are of the **relict type (residual hills).**
- They are the remnants of the hills and horsts formed many million years ago (horst: uplifted block; graben: subsided block).
- The plateaus of the Peninsular region are separated from one another by these hill ranges and various river valleys.

Aravali Range

- They are aligned in north-east to south-west direction.
- They run for about 800 km between **Delhi** and Palanpur in **Gujarat.**
- They are one of the **oldest (very old) fold mountains** of the world and the oldest in India. {Fold Mountains – Block Mountains}
- After its formation in Archaean Era (several 100 million years ago), its summits were nourishing glaciers and several summits were probably higher than the present day Himalayas.
- Now they are relict (remnants after severe weathering and erosion since millions of years) of the world's oldest mountain formed as a result of folding (Archaean Era).
- They continue up to **Hariddwar** buried under the alluvium of Ganga Plains.



- The range is conspicuous in Rajasthan (continuous range south of Ajmer where it rises to 900 m.) but becomes less distinct in Haryana and Delhi (characterized by a chain of detached and discontinuous ridges beyond Ajmer).
- According to some geographers, one Branch of the Aravalis extends to the Lakshadweep Archipelago through the Gulf of Khambhat and the other into Andhra Pradesh and Karnataka.
- It's general elevation is only 400-600 m, with few hills well above 1,000 m.
- At the south-west extremity the range rises to over 1,000 m. Here **Mt. Abu (1,158 m)**, a small hilly block, is separated from the main range by the **valley of the Banas**. **Guru Sikhar (1,722**

m), the highest peak, is situated in Mt. Abu.

- **Pipli Ghat**, Dewair and Desuri passes allow movement by roads and railways.

Vindhyan Range

- The Vindhyan Range, overlooking (have a view of from above) the Narmada valley, rises as an escarpment (a long, steep slope at the edge of a plateau or separating areas of land at different heights) flanking (neighboring on one side) the northern edge of the Narmada-Son Trough (the rift through which the Narmada river flows)(trough is opposite of ridge. It is a narrow depression).
- It runs more or less parallel to the **Narmada Valley** in an east-west direction from Jobat in Gujarat to Sasaram in Bihar for a distance of over 1,200 km.
- The general elevation of the Vindhyan Range is 300 to 650 m.
- Most parts of the Vindhayan Range are composed of horizontally bedded sedimentary rocks of ancient age. {Rock System}
- The Vindhyas are continued eastwards as the **Bharner** and **Kaimur hills**.
- This range acts as a watershed between the Ganga system and the river systems of south India.
- The rivers **Chambal, Betwa** and **Ken** rise within 30 km of the Narmada.

Satpura Range

- Satpura range is a series of seven mountains ('Sat' = seven and 'pura' = mountains)
- It runs in an east-west direction south of the Vindhyas and in between the Narmada and the Tapi, roughly parallel to these rivers.
- It stretches for a distance of about 900 km.
- Parts of the Satpuras have been folded and upheaved. They are regarded as structural uplift or **'horst'**.
- **Dhupgarh (1,350 m)** near **Pachmarhi on Mahadev Hills** is the highest peak.
- **Amarkantak (1,127 m) is another important peak.**

Western Ghats (or The Sahyadris)

- They form the western edge of the Deccan tableland.
- Run from the Tapi valley (21° N latitude) to a little north of Kanniyakumari (11° N latitude) for a distance of 1,600 km.
- The Western Ghats are steep-sided, terraced, flat-topped hills presenting a stepped topography facing the Arabian Sea coast.
- This is due to the horizontally bedded lavas, which on weathering, have given a characteristic **'landing stair aspect'** to the relief of this mountain chain.
- The Western Ghats abruptly rise as a sheer wall to an average elevation of 1,000 m from the Western Coastal Plain.
- But they slope gently on their eastern flank and hardly appear to be a mountain when viewed from the Deccan tableland.
- South of Malabar, the Nilgiris, Anamalai, etc. present quite different landscape due to the difference in geological structure.

The northern section

- The northern section of the Ghats from Tapi valley to a little north of Goa is made of horizontal sheets of **Deccan lavas (Deccan Traps)**.
- The average height of this section of the Ghats is 1,200 m above mean sea level, but some peaks attain more heights.
- **Kalasubai (1,646 m)** near Igatpuri, Salher (1,567 m) about 90 km north of Nashik, Mahabaleshwar (1,438 m) and Harishchandragarh (1,424 m) are important peaks.
- Thal ghat and Bhor ghat are important passes which provide passage by road and rail between the **Konkan Plains** in the west and the Deccan Plateau in the east.

[Konkan coast == Maharashtra coast and Goa coast;

Malabar Coast == Kerala and Karnataka coast]

The Middle Sahyadri

- The Middle Sahyadri runs from 16°N latitude upto Nilgiri hills.
- This part is made of granites and gneisses.
- This area is covered with **dense forests**.
- The western scarp is considerably dissected by headward erosion of the west flowing streams.
- The average height is 1200 m but many peaks exceed 1500 m.
- The **Vavul Mala (2,339 m)**, the **Kudremukh (1,892 m)** and **Pashpagiri (1,714 m)** are important peaks.
- The Nilgiri Hills which join the Sahyadris near the trijunction of Karnataka, Kerala and TN, rise abruptly to over 2,000 m.
- They mark the junction of the Western Ghats with Eastern Ghats.
- **Doda Betta (2,637 m) and Makurti (2,554 m)** are important peaks of this area.

The southern section

- The southern part of the Western Ghats is separated from the main Sahyadri range by **Pal ghat Gap** [**Palakkad Gap**].
- The high ranges terminate abruptly on either side of this gap.
- **Pal ghat Gap** it is a **rift valley**. This gap is used by a number of roads and railway lines to connect the plains of Tamil Nadu with the coastal plain of Kerala.
- It is through this gap that moist-bearing clouds of the south-west monsoon can penetrate some distance inland, bringing rain to Mysore region.
- South of the Pal ghat Gap there is an intricate system of steep and rugged slopes on both the eastern and western sides of the Ghats.
- **Anai Mudi (2,695 m)** is the highest peak in the whole of southern India.
- Three ranges radiate in different directions from Anai Mudi. These ranges are the **Anaimalai (1800-2000 m)** to the north, the **Palani (900-1,200 m)** to the north-east and the **Cardamom Hills** or the **Ealaimalai** to the south.

Eastern Ghats

- Eastern Ghats run almost parallel to the east coast of India leaving broad plains between their base and the coast.
- It is a chain of highly broken and detached hills starting from the **Mahanadi** in Odisha to the **Vagai** in Tamil Nadu. They almost disappear between the Godavari and the Krishna.
- They neither have structural unity nor physiographic continuity. Therefore these hill groups are generally treated as independent units.
- It is only in the northern part, between the Mahanadi and the Godavari that the Eastern Ghats exhibit true mountain character. This part comprises the **Maliya** and the **Madugula Konda** ranges.
- The peaks and ridges of the Maliya range have a general elevation of 900-1,200 m and **Mahendra Giri (1,501 m)** is the tallest peak here.
- The Madugula Konda range has higher elevations ranging from 1,100 m and 1,400 m with several peaks exceeding 1,600 m**. Jindhagada Peak (1690 m)** in Araku Valley **Arma Konda (1,680 m), Gali Konda (1,643 m) and Sinkram Gutta (1,620 m)** are important peaks.
- Between the Godavari and the Krishna rivers, the Eastern Ghats lose their hilly character and are occupied by **Gondwana formations** (KG Basin is here).
- The Eastern Ghats reappear as more or less a continuous hill range in Cuddapah and Kurnool districts of Andhra Pradesh where they are called as **Nallamalai Range** [Naxalite hideout in AP] with general elevation of 600-850 m.
- The southern part of this range is called the **Palkodna range**.
- To the south, the hills and plateaus attain very low altitudes; only **Javadi Hills** and the **Shevroy-Kalrayan Hills** form two distinct features of 1,000 m elevation.

- The **Biligiri Rangan Hills** in Coimbatore district attain a height of 1,279 m.
- Further south, the Eastern Ghats merge with the Western Ghats.

Significance of the Peninsular Plateau

- There are huge deposits of iron, manganese. copper, bauxite, chromium, mica, gold, etc.
- 98 per cent of the Gondwana coal deposits of India are found in the Peninsular Plateau.
- Besides there are large reserves of slate, shale, sandstones, marbles, etc.
- A large part of north-west plateau is covered with fertile black lava soil which is extremely useful for growing cotton.
- Some hilly regions in south India are suitable for the cultivation of plantation crops like **tea, coffee, rubber, etc**..
- Some low lying areas of the plateau are suitable for growing rice.
- The highlands of the plateau are covered with different types of forests which provide a large variety of forest products.
- The rivers originating in the Western Ghats offer great opportunity for developing hydroelectricity and providing irrigation facilities to the agricultural crops.
- The plateau is also known for its hill resorts such as **Udagamangalam (Ooty), Panchmarhi, Kodaikanal, Mahabaleshwar, Khandala, Matheron, Mount Abu,** etc.

In this post: Coastline of India – Indian Coastline - East Coast of India, West Coast of India, Coastlines: Coastlines of Emergence and Submergence; Western Coastal Plains Kutch and Kathiawar region: Gujarat Plain, Konkan Plain, Karnataka Coastal Plain and Kerala Plain; Eastern Coastal Plains of India: Utkal Plain, Andhra Plain and Tamil Nadu Plain; Significance of the Coastal Plains.

Coastline of India – Indian Coastline

- India has a coastline of **7516.6 Km [6100 km of mainland coastline + coastline of 1197 Indian islands]** touching 13 States and Union Territories (UTs).
- The straight and regular coastline of India is the result of faulting of the Gondwanaland during the Cretaceous period. {**Continental Drift**}
- As such the coast of India **does not offer many sites for good natural harbours.**

[**Indented coastlines of Europe provide good natural harbours whereas African and Indian coastlines are not indented**].

- The Bay of Bengal and the Arabian Sea came into being during the **Cretaceous or early Tertiary period after the disintegration of Gondwanaland.**

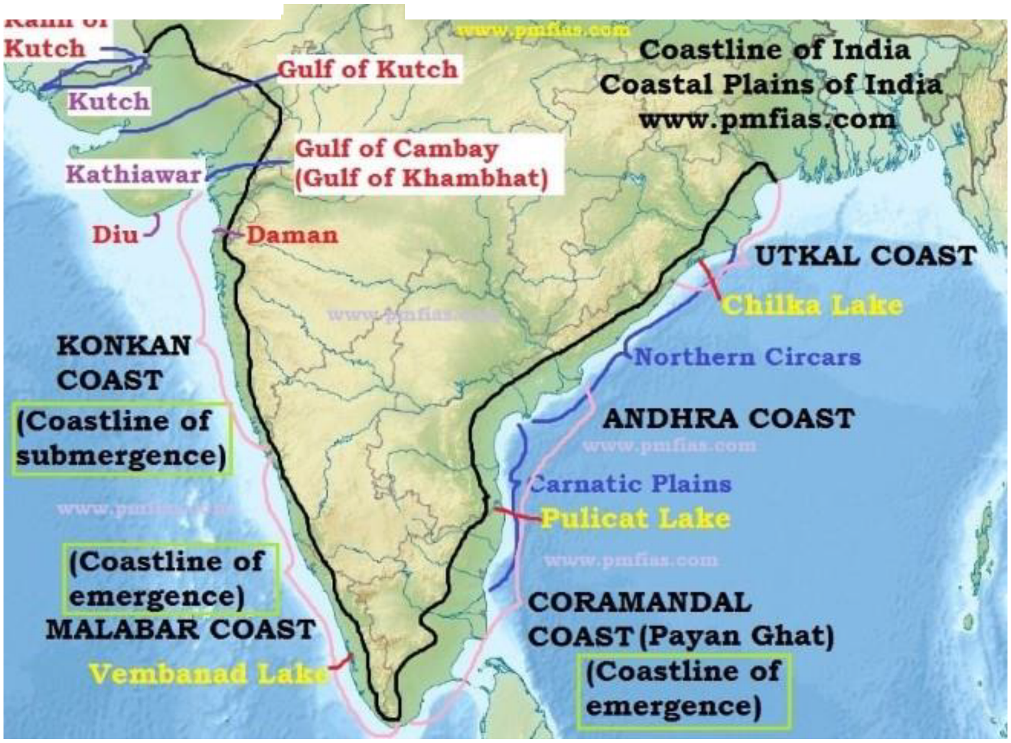
East Coast of India

- Lies between the Eastern Ghats and the Bay of Bengal.
- It extends from the Ganga delta to Kanniyakumari.
- It is marked by deltas of rivers like the Mahanadi, the Godavari, the Krishna and the Cauvery.
- **Chilka lake** and the **Pulicat lake (lagoon)** are the important geographical features of east coast.

Regional Names of The East Coast of India

- In Orissa (Odisha) it is known as **Utkal coast**.
- From the southern limit of the Utkal plain, stretch the **Andhra coast**.
- In the south of the Andhra plain is the **Tamil Nadu coast.**
- The Tamil Nadu coast and parts of Andhra coast together are known as **Coramandal Coast** or **Payan Ghat** [False Divi Point in AP (Krishna River Delta) in the north to Kanyakumari in the south.].

West Coast of India



- The west coast strip extends from the **Gulf of Cambay (Gulf of Khambhat)** in the north to **Cape Comorin** (Kanniyakumari).
- Starting from north to south, it is divided into (i) the **Konkan coast**, (ii) the **Karnataka coast** and (iii) the **Kerala cost**.
- It is made up of alluvium brought down by the **short streams** originating from the Western Ghats.
- It is dotted with a large number of **coves (a very small bay), creeks (**a narrow, sheltered waterway such as an inlet in a shoreline or channel in a marsh**) and a few estuaries**. {Marine Landforms}
- The **estuaries, of the Narmada and the Tapi** are the major ones.
- The Kerala coast (**Malabar Coast**) has some **lakes, lagoons and backwaters**, the largest being the **Vembanad Lake**.

Regional Names of The West Coast of India

- **Konkan coast == Maharashtra coast and Goa coast;**
- **Malabar Coast == Kerala and Karnataka coast.**

Coastlines

Already explained in Marine Landforms. I am discussing here for continuity.

1. Coastline of Emergence
2. Coastline of Submergence

Coastlines of Emergence and Submergence

Coastline of emergence is formed either by an uplift of the land or by the lowering of the sea level. Coastline of submergence is an exact opposite case. **Bars, spits, lagoons, salt marshes, beaches, sea cliffs and arches** are the typical features of emergence. {Marine Landforms}

- The east coast of India, especially its south-eastern part (Tamil Nadu coast), appears to be a coast of emergence.
- The west coast of India, on the other hand, is both emergent and submergent.
- The northern portion of the coast is submerged as a result of faulting and the southern portion, that is the Kerala coast, is an example of an emergent coast.

1. **Coramandal coast (Tamil Nadu) ==> Coastline of emergence**
2. **Malabar coast (Kerala Coast) ==> Coastline of emergence**
3. **Konkan coast (Maharashtra and Goa Coast) ==> Coastline of submergence.**

Western Coastal Plains of India

- Rann of Kachchh in the north to Kanniyakumari in the South.
- These are **narrow plains** with an average width of about **65 km.**

Kutch and Kathiawar region

- Kutch and Kathiawar, though an extension of Peninsular plateau (because Kathiawar is made of the Deccan Lava and there are tertiary rocks in the Kutch area), they are still treated as integral part of the Western Coastal Plains as they are now levelled down.
- The Kutch Peninsula was an island surrounded by seas and lagoons. These

seas and lagoons were later filled by sediment brought by the Indus River which used to flow through this area. Lack of rains in recent times has turned it into arid and semi-arid landscape.

- Salt-soaked plain to the north of Kutch is the **Great Rann**. Its southern continuation, known as the **Little Rann** lies on the coast and south-east of Kachchh.
- The Kathiawar Peninsula lies to the south of the Kachchh. The central part is a highland of **Mandav Hills** from which small streams radiate in all directions (**Radial Drainage**). **Mt. Girnar (1,117 m)** is the highest point and is of volcanic origin.
- The **Gir Range** is located in the southern part of the Kathiawar peninsula. It is covered with dense forests and is famous as home of the **Gir lion.**

Gujarat Plain

- The Gujarat Plain lies east of Kachchh and Kathiawar and slopes towards the west and south west.
- Formed by the rivers **Narmada, Tapi, Mahi** and **Sabarmati**, the plain includes the southern part of Gujarat and the coastal areas of the Gulf of Khambhat.
- The eastern part of this plain is fertile enough to support agriculture, but the greater part near the coast is covered by windblown loess (heaps of sand).

Konkan Plain

- The Konkan Plain south of the Gujarat plain extends from Daman to Goa (50 to 80 km wide).
- It has some features of marine erosion including cliffs, shoals, reefs and islands in the Arabian Sea.
- The **Thane creek** around Mumbai is an important embayment (a recess in a coastline forming a bay) which provides an **excellent natural harbour**.

Karnataka Coastal Plain

- Goa to Mangalore.
- It is a **narrow plain** with an average width of 30-50 km, the maximum being 70 km near Mangalore.
- At some places the streams originating in the Western Ghats descend along steep slopes and make waterfalls.
- The **Sharavati** while descending over such a steep slope makes an impressive waterfall known as **Gersoppa (Jog) Falls** which is **271 m high.** [**Angel falls** (979 m) in Venezuela is the highest waterfall on earth. **Tugela Falls** (948 m) in Drakensberg mountains in South Africa is the second highest.]
- Marine topography is quite marked on the coast.

Kerala Plain

- The Kerala Plain also known as the **Malabar Plain**.
- Between Mangalore and Kanniyakumari.
- This is much **wider** than the Karnataka plain. It is a low lying plain.
- The existence of lakes, lagoons, backwaters, spits, etc. is a significant characteristic of the Kerala coast.
- The backwaters, locally known as **kayals** are the shallow **lagoons or inlets** of the sea, lying parallel to the coastline.
- The largest among these is the **Vembanad Lake** which is about 75 km long and 5-10 km wide and gives rise to a 55 km long spit {Marine Landforms}.

Eastern Coastal Plains of India

- Extending from the **Subarnarekha** river along the West Bengal-Odisha border to Kanniyakumari.
- A major part of the plains is formed as a result of the alluvial fillings of the littoral zone (relating to or on the shore of the sea or a lake) by the rivers Mahanadi, Godavari, Krishna and Cauvery comprising some of the largest deltas.
- In contrast to the West Coastal Plains, these are **extensive plains** with an average width of 120 km.

- This plain is known as the **Northern Circars** between the Mahanadi and the Krishna rivers and **Carnatic** between the Krishna and the Cauvery rivers.

Utkal Plain

- The Utkal Plain comprises coastal areas of Odisha.
- It includes the Mahanadi delta.
- The most prominent physiographic feature of this plain is the **Chilka Lake.**
- It is the **biggest lake** in the country and its area varies between 780 sq km in winter to 1,144 sq km in the monsoon months.
- South of Chilka Lake, low hills dot the plain.

Andhra Plain

- South of the Utkal Plain and extends upto **Pulicat Lake.** This lake has been barred by a long sand spit known as **Sriharikota Island** (ISRO launch facility).
- The most significant feature of this plain is the delta formation by the rivers Godavari and Krishna.
- The two deltas have merged with each other and formed a single physiographic unit.
- The combined delta has advanced by about 35 km towards the sea during the recent years. This is clear from the present location of the **Kolleru Lake** which was once a lagoon at the shore but now lies far inland {Coastline of Emergence}.
- This part of the plain has a straight coast and badly lacks good harbours with the exception of **Vishakhapatnam** and **Machilipatnam.**

Tamil Nadu Plain

- The Tamil Nadu Plain stretches for 675 km from Pulicat lake to Kanniyakumari along the coast of Tamil Nadu. Its average width is 100 km.
- The most important feature of this plain is the Cauvery delta where the plain is 130 km wide.
- The fertile soil and large scale irrigation facilities have made the Cauvery delta the granary of South India.

Significance of the Coastal Plains

- Large parts of the coastal plains of India are covered by fertile soils on which different crops are grown. Rice is the main crop of these areas.
- Coconut trees grow all along the coast.
- The entire length of the coast is dotted with big and small ports which help in carrying out trade.
- The sedimentary rocks of these plains are said to contain large deposits of mineral oil (KG Basin).
- The sands of Kerala coast have large quantity of **MONAZITE** which is used for **nuclear power.**
- Fishing is an important occupation of the people living in the coastal areas.
- Low lying areas of Gujarat are famous for producing salt.
- Kerala backwaters are important tourist destinations.
- Goa provides good beaches. This is also an important tourist destination.

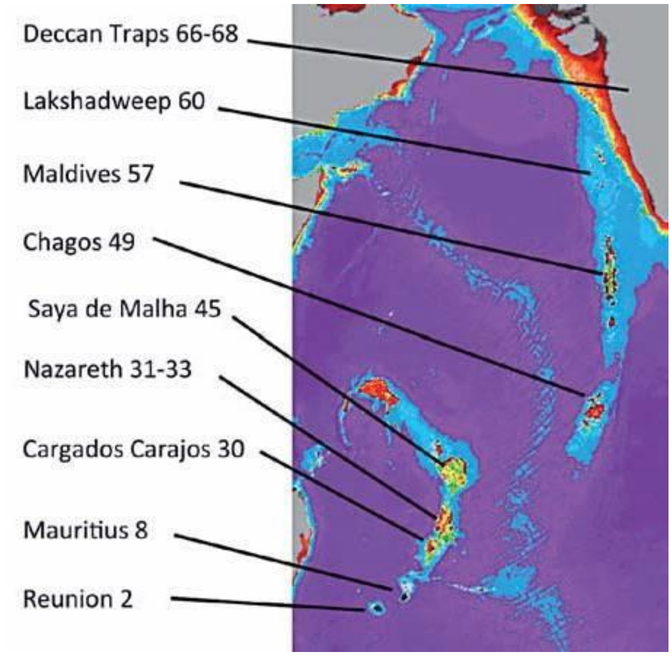
In this post: Indian Islands - Andaman and Nicobar islands - Lakshadweep Islands - New Moore Island.

Indian Islands

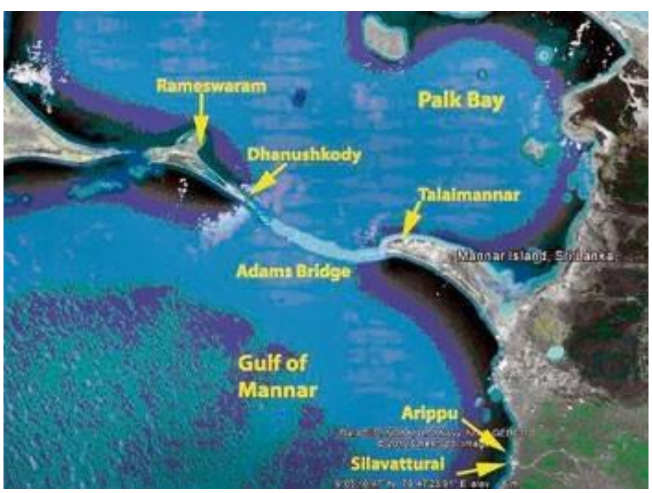
- The major islands groups of India are Andaman and Nicobar Archipelago (A chain of islands similar in origin) in Bay of Bengal and Lakshadweep islands in Arabian Sea.
- Andaman and Nicobar Islands were formed due to **collision between Indian Plate and Burma Minor Plate [part of Eurasian Plate][Similar to formation of Himalayas].**
- Andaman and Nicobar Islands are southward extension of **Arakan Yoma range [Myanmar][Arakan Yoma in itself is an extension of Purvanchal Hills**].
- Lakshadweep Islands are **coral islands**. These islands are a part **Reunion Hotspot**

volcanism. [Both these concepts are explained in previous posts]

Island Groups of Reunion Hotspot



- Other than these two groups there are islands in Indo-Gangetic Delta [they are more a part of delta than islands] and between India and Sri Lanka [Remnants of Adams Bridge; formed due to submergence].



Andaman and Nicobar islands

- This archipelago is composed of 265 big and small islands [203 Andaman islands + 62 Nicobar Islands][*Numbers are just for understanding. You need not remember trivial facts*].
- The Andaman and Nicobar islands extend from 6° 45' N to 13° 45' N and from 92° 10' E to 94° 15' E for a distance of about 590 km.
- The Andaman islands are divided into three main islands i.e. **North, Middle** and **South.**
- **Duncan passage** separates Little Andaman from South Andaman.
- The Great Andaman group of islands in the north is separated by the **Ten Degree Channel** from the Nicobar group in the south [*Prelims 2014*].
- **Port Blair**, the capital of Andaman Nicobar Islands lies in the South Andaman.
- Among the Nicobar islands, the **Great Nicobar** is the largest. It is the southernmost island and is very close to Sumatra island of Indonesia. The **Car Nicobar** is the northernmost.
- Most of these islands are made of tertiary sandstone, limestone and shale resting on basic and ultrabasic volcanoes [Similar to Himalayas].
- **THE BARREN AND NARCONDAM ISLANDS**, north of Port Blair, are **volcanic islands [these are the only active volcanoes in India][There are no active volcanoes in main land India]**.
- Some of the islands are fringed with **coral reefs**. Many of them are covered with thick forests. Most of the islands are mountainous.
- **Saddle peak (737 m)** in **North Andaman** is the highest peak.

Lakshadweep Islands

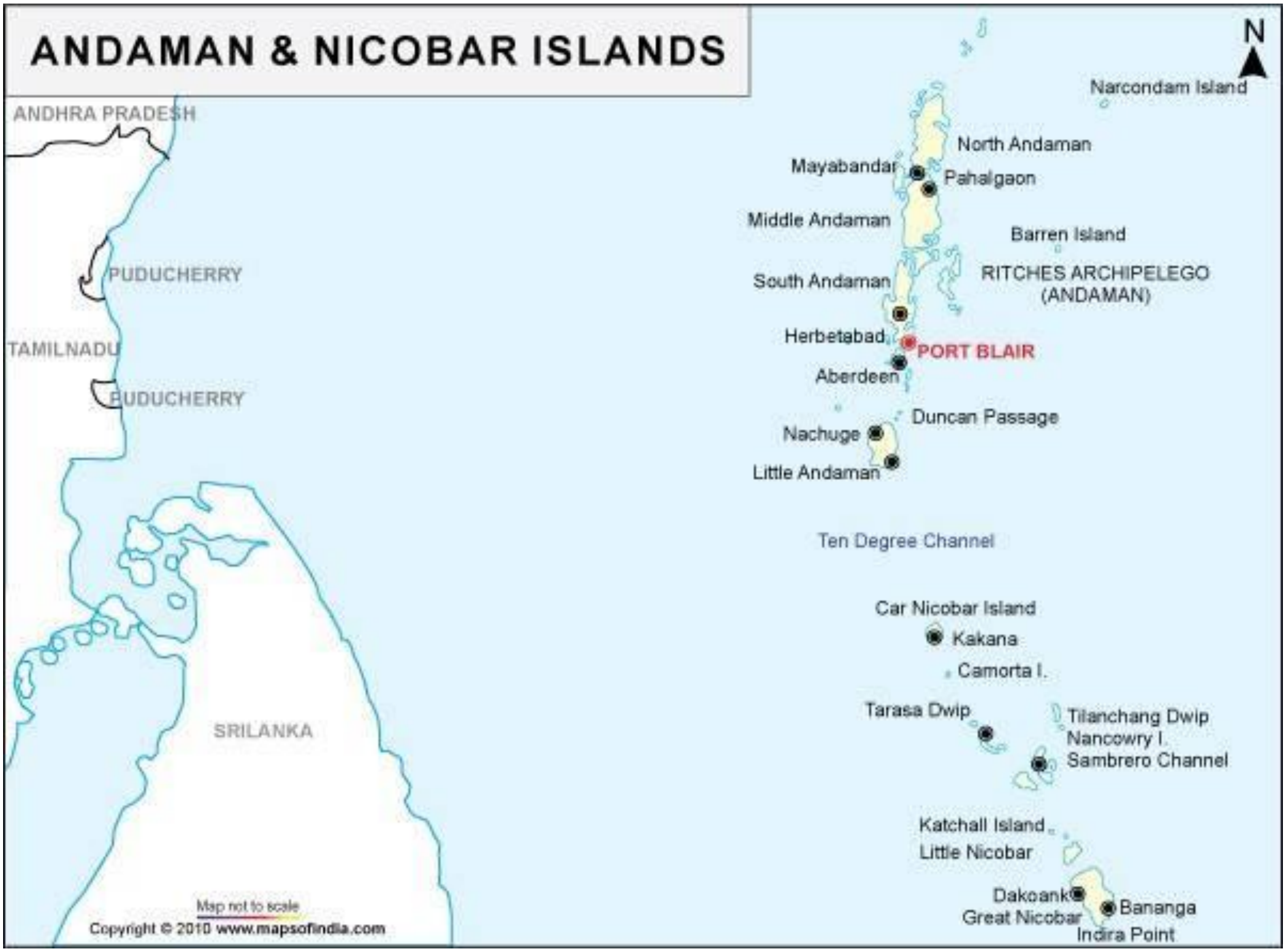
- In the Arabian Sea, there are three types of islands.

(1) **Amindivi Islands** (consisting of six main islands of Amini, Keltan, Chetlat, Kadmat, Bitra and Perumul Par). [*don't have to remember all these names*]

(2) **Laccadive Islands** (consisting of five major islands of Androth, Kalpeni, **Kavaratti**, Pitti and Suheli Par) and

(3) **Minicoy**.

- At present these islands are collectively known as Lakshadweep.
- The Lakshadweep Islands are a group of 25 small islands.



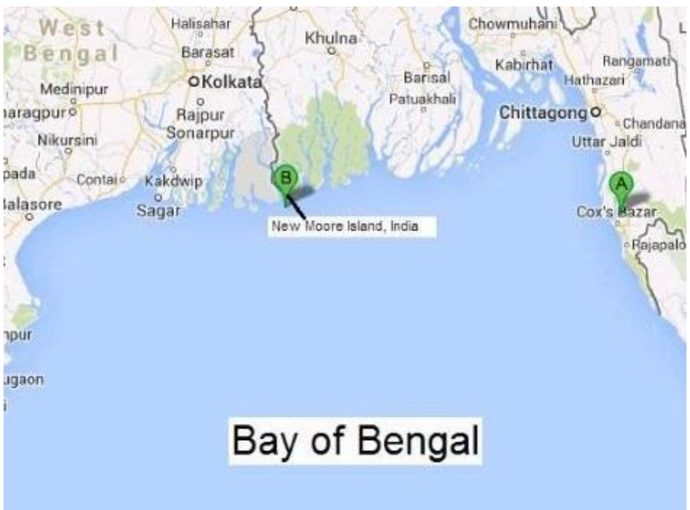
- They are widely scattered about 200-500 km south-west of the Kerala coast.
- **Amendivi Islands** are the northern most while the **Minicoy island is the southernmost**.
- All are tiny islands of coral origin {Atoll} and are surrounded by **fringing reefs**.
- The largest and the most advanced is the **Minicoy island** with an area of 4.53 sq km.
- Most of the islands have low elevation and do not rise more than five metre above sea level (Extremely Vulnerable to sea level change).
- Their topography is flat and relief features such as hills, streams, valleys, etc. are **absent.**

New Moore Island

- It is a small uninhabited offshore sandbar landform {Marine Landforms} in the Bay of

Bengal, off the coast of the Ganges-Brahmaputra Delta region.

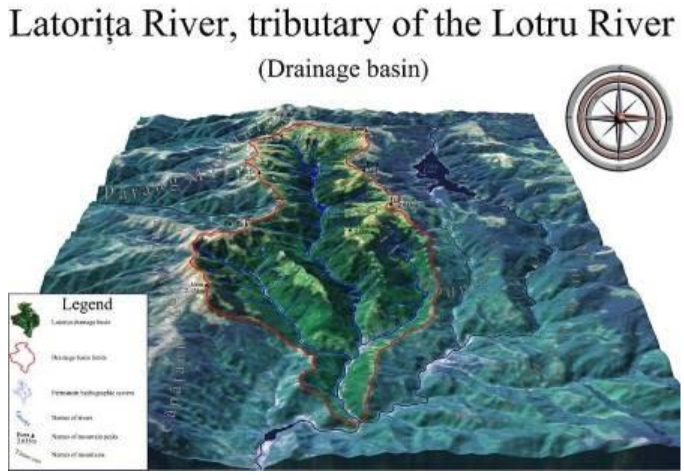
- It emerged in the Bay of Bengal in the aftermath of the **Bhola cyclone in 1970**. It keeps on emerging and disappearing.
- Although the island was uninhabited and there were no permanent settlements or stations located on it, both **India and Bangladesh claimed sovereignty over it because of speculation over the existence of oil and natural gas in the region**.
- The issue of sovereignty was also a part of the larger dispute over the **Radcliffe Award** methodology of settling the maritime boundary between the two nations



Drainage basin, Drainage Divide, Difference between a River Basin and a Watershed. Drainage patterns – Discordant drainage patterns and Concordant Drainage Patterns.

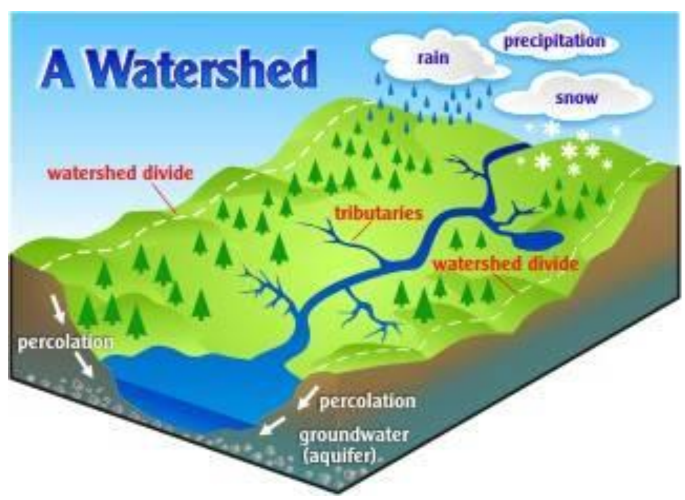
Drainage basin

- 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 channeling it to a single point.



- In **closed ("endorheic") drainage** basins the water converges to a single point inside the basin, known as a **sink**, which may be a permanent lake [Lake Aral], dry lake [some desert lakes], or a point where surface water is lost underground [sink holes in Karst landforms]. Other Examples: Lake Chad [Africa], Dead Sea etc.

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 [Ganga plains] and **senile topography** [old featureless landforms – Rolling plateaus of Peninsular

region though which South Indian rivers flow].

Some important drainage basins across the world

This is Wiki stuff. So can't guarantee accuracy..

Basin	Type	Continent	Drains to	Basin Area km²
Amazon River	Primary River	South America	Atlantic Ocean	6,144,727
Hudson Bay	Mediterranean sea	North America	Atlantic Ocean	3,861,400
Congo River	Primary River	Africa	Atlantic Ocean	3,730,474
Caspian Sea	Lake	Asia/Europe	**(endorheic basin == not outlet)**	3,626,000
Nile River	Primary River	Africa	Mediterranean Sea	3,254,555
Mississippi-Missouri River	Primary River	North America	Gulf of Mexico	3,202,230
Lake Chad	Lake	Africa	n/a (endorheic basin)	2,497,918
Black Sea	Mediterranean sea	multiple	Mediterranean Sea	2,400,000
Niger River	Primary River	Africa	Atlantic Ocean	2,261,763
Yangtze River (Chang Jiang)	Primary River	Asia	Pacific Ocean	1,722,155
Baltic Sea	Mediterranean sea	Europe	Atlantic Ocean[4]	1,700,000
Ganges–Brahmaputra	Primary River	Asia	Bay of Bengal	1,621,000
Indus River	Primary River	Asia	Arabian Sea	1,081,733

Difference between a River Basin and a Watershed

- Both river basins and watersheds are areas of land that drain to a particular water body, such as a lake, stream, river or estuary.

- In a river basin, all the water drains to a large river. The term watershed is used to describe a smaller area of land that drains to a smaller stream, lake or wetland. There are many smaller watersheds within a river basin.
- Example: watershed of Yamuna + water shed of Chambal + watershed of Gandak + …. = Drainage basin of Ganga.

Drainage patterns

- Based on the shape and formation of river patters, there are different drainage patterns.

Discordant drainage patterns

- A drainage pattern is described as discordant if it **does not correlate to the topology [surface relief features]** and **geology** [geological features based on both Endogenetic movements and exogenetic movements] of the area.
- In simple words: *In a discordant drainage pattern, the river follows its initial path irrespective of the changes in topography*.
- Discordant drainage patterns are classified into two main types: **antecedent** and **superimposed**.

Antecedent Drainage or Inconsequent Drainage

- A part of a river slope and the surrounding area gets uplifted and the river **sticks to its original slope**, cutting through the uplifted portion like a saw [Vertical erosion or Vertical down cutting], and forming deep gorges: this type of drainage is called **Antecedent drainage.**

Example: **Indus, Sutlej, Brahmaputra and other Himalayan rivers that are older than the Himalayas themselves. There are usually called as *ANTECEDENT RIVERS.***

Superimposed or Epigenetic (Discordant) or Superinduced Drainage

- When a river flowing over a softer rock stratum reaches the harder basal rocks but continues to follow the initial slope, it seems to have no relation with the harder rock bed. This type of drainage is called **superimposed drainage**.
- Usually, the drainage patterns (dendritic, trellis, etc.) are strongly influenced by the hardness and softness of the rock and patterns of faults or fractures.
- Sometimes, however, the land rises rapidly relative to the base level of the stream. This increases the gradient of the stream and therefore, gives the stream more erosive power.
- The stream has enough erosive power that it cuts its way through any kind of bedrock, **maintaining its former drainage pattern**.
- You get a situation, then, where the drainage pattern does not correspond to the hardness or softness of the bedrock or to the locations of faults and fractures.
- In other words, it is a drainage pattern which exhibits discordance with the underlying rock structure because it originally developed on a cover of rocks that has now disappeared due to denudation.
- Consequently, river directions relate to the former cover rocks and, as the latter were being eroded, the rivers have been able to retain their courses unaffected by the newly exposed structures.

The stream pattern is thus superposed on, or placed on structural features that were previously buried.

- The **Damodar**, the **Subarnarekha**, the **Chambal**, the **Banas** and the rivers flowing at the **Rewa Plateau** present some good examples of superimposed drainage.
- Examples: **The Damodar, the Subarnarekha, the Chambal, the Banas and the rivers flowing at the Rewa Plateau, rivers of eastern USA and southern France.**
- [In simple words, the river flow becomes independent of present Topography. It

flows in its initial paths without being influenced by changing topography].

Antecedent Drainage == Cut through the newly formed landform and maintain the same path == Himalayan Rivers.

Superimposed Drainage == Cut deeper through the existing landform and maintain the same path == Some medium scale rivers of the Northern and Eastern peninsular India.

Antecedent Drainage == The soil formed is weak and it is easily eroded by the rivers.

Superimposed Drainage == The rivers have high erosive power so that they can cut through the underlying strata.

Usually, rivers in both these drainage types flow through a highly sloping surface.

Concordant Drainage Patterns

- A drainage pattern is described as concordant if it **correlates to the topology** and **geology** of the area.
- In simple words: *In a concordant drainage pattern, the path of the river is highly dependent on the slope of the river and topography.*
- Concordant drainage patterns are the most commonly found drainage patterns and are classified into many types.

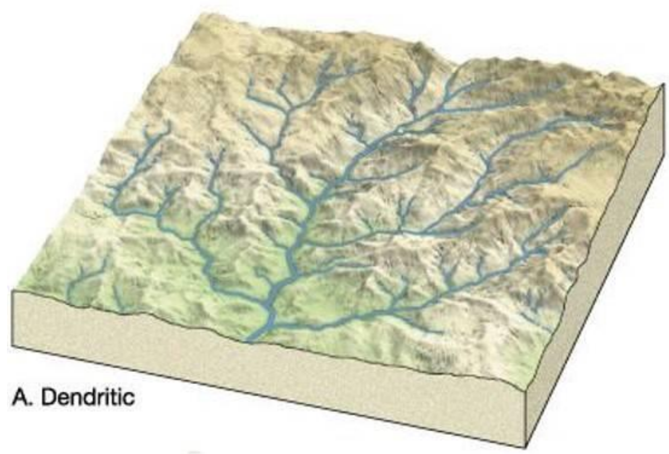
Consequent Rivers

- The rivers which follow the **general direction of slope** are known as the consequent rivers.
- Most of the rivers of peninsular India are consequent rivers.
- For example, rivers like **Godavari, Krishna and Cauvery,** descending from the Western Ghats and flowing into the Bay of Bengal, are some of the consequent rivers of Peninsular India.

Subsequent Rivers

- A tributary stream that is eroded **along** an underlying belt of non-resistant rock after the main drainage pattern (Consequent River) has been established is known as a subsequent river.
- The **Chambal, Sind, Ken, Betwa, Tons and Son** meet the Yamuna and the Ganga at right angles. They are the subsequent drainage of the Ganga drainage system.
- These streams have generally developed **after the original stream**.

Dendritic or Pinnate Drainage Pattern

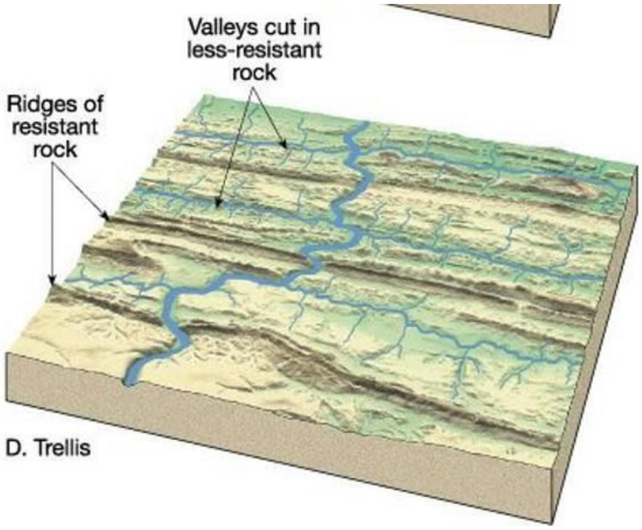


A. Dendritic

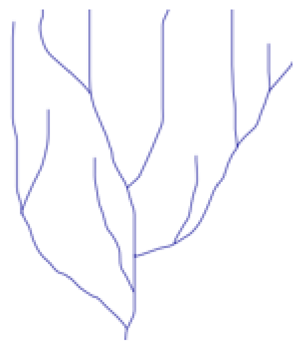
- This is an irregular tree branch shaped pattern.
- Drainage which is branching or ramifying (branch out or cause to branch out) thereby giving the appearance of a tree.
- A dendritic pattern develops in a terrain which has uniform lithology, and where faulting and jointing are insignificant.
- Examples**: Indus, Godavari, Mahanadi, Cauvery, Krishna.**

Trellis Drainage Pattern

- In this type of pattern the short subsequent streams meet the main stream at **right angles**, and differential erosion through soft rocks paves the way for tributaries.
- Examples: The old folded mountains of the **Singhbhum (Chotanagpur Plateau)** and **Seine and its tributaries in Paris basin (France)** have a drainage of trellis pattern.

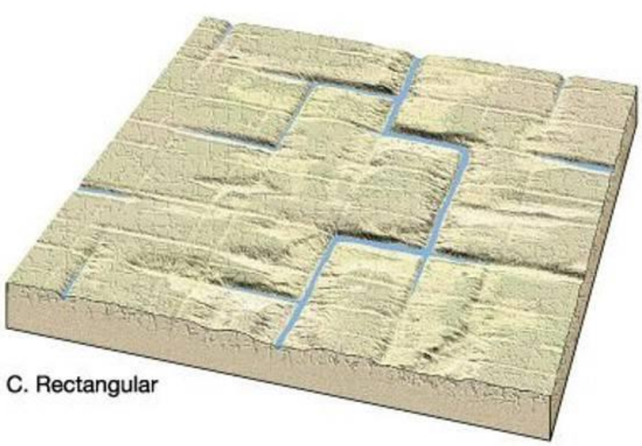


Angular Drainage Pattern



- The tributaries join the main stream at acute angles.
- This pattern is common in **Himalayan foothill regions.**

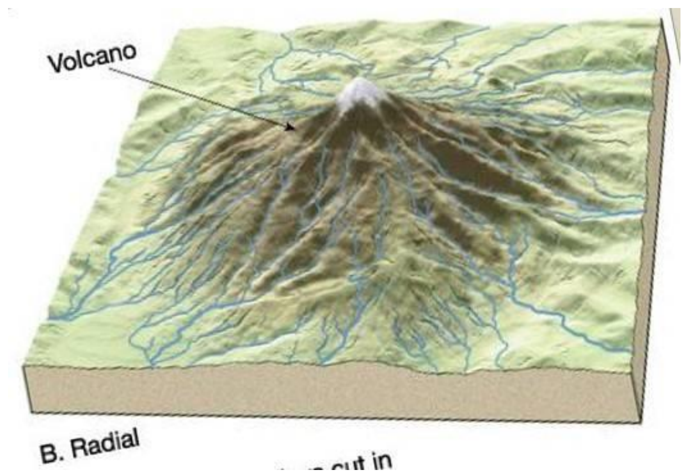
Rectangular Drainage Pattern



- The main stream **bends at right angles** and the tributaries **join at right angles** creating rectangular patterns.
- This pattern has a subsequent origin.
- Example: **Colorado river (USA),** streams found is the Vindhyan Mountains of India.

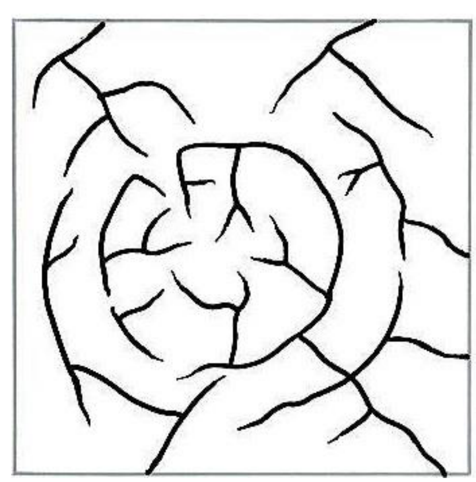
Radial Drainage Pattern

- The tributaries from a summit follow the slope downwards and drain down in all directions.
- Examples: **Streams of Saurashtra region, Central French Plateau, Mt. Kilimanjaro.**
- A good example of a radial drainage pattern is provided by the **rivers originating from the Amarkantak Mountain.**



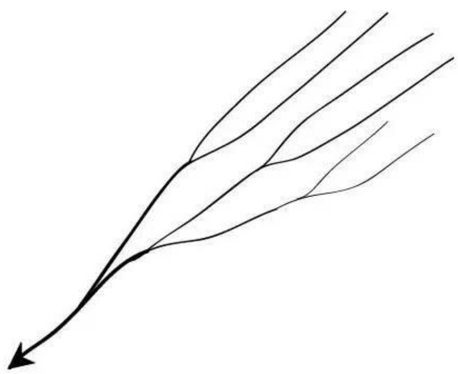
- Rivers like Narmada, Son and Mahanadi originating from Amarkantak Hills flow in different directions and are good examples of radial pattern.
- Radial drainage patterns are also found/in the Girnar Hills (Kathiwar, Gujarat), and Mikir Hills of Assam.

Annular Drainage Pattern



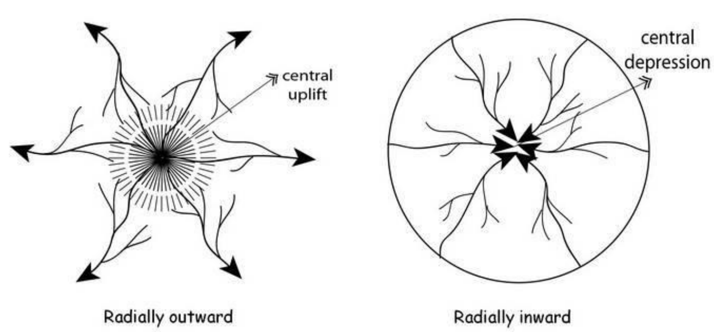
- When the upland has an outer soft stratum, the radial streams develop subsequent tributaries which try to follow a circular drainage around the summit.
- Example: Black Hill streams of South Dakota.
- This is not a very common drainage pattern in India. Some examples of this are however found in **Pithoragarh (Uttarakhand), Nilgiri Hills in Tamil Nadu and Kerala**.

Parallel Drainage Pattern



- The tributaries seem to be running parallel to each other in a uniformly sloping region.
- Example: **Rivers of lesser Himalayas** and The **small and swift rivers originating in the Western Ghats** that flow into Arabian Sea.

Centripetal Drainage Pattern



- In a low lying basin the streams converge from all sides.
- Examples: **streams of Ladakh, Tibet**, and the **Baghmati** and its tributaries in Nepal.

Deranged Drainage Pattern

- This is an uncoordinated pattern of drainage characteristic of a region recently vacated by an ice-sheet.
- This type of drainage is found in the glaciated valleys of **Karakoram**.

Barbed Drainage Pattern

- A pattern of drainage in which the confluence of a tributary with the main river is characterized by a discordant junction—as if the tributary intends to flow upstream and not downstream.
- This pattern is the result of capture of the main river which completely reverses its direction of flow, while the tributaries continue to point in the direction of former flow.
- The Arun River (Nepal), a tributary of the Kosi is an interesting example of barbed drainage pattern.

In this post: Contribution of Water by Various Rivers, Classification of Drainage Systems of India and Major River System or Drainage Systems in India.

Contribution of Water by Various Rivers

River	% Contribution of water
Brahmaputra	**~ 40**
Ganga	**~ 25**
Godavari	**~ 6.4**
Mahanadi	**~ 3.5**
Krishna	**~ 3.4**
Narmada	**~ 2.9**
Rest	**~ 20**

Classification of Drainage Systems of India

Drainage Systems Based on the Size of the Catchment Area

Division	Size of catchment area in sq km
Major river	**20,000**
Medium river	**20,000 – 2,000**
Minor river	**2,000 and below**

Drainage Systems Based on Origin

- The Himalayan Rivers: **Perennial rivers**: Indus, the Ganga, the Brahmaputra and their tributaries.
- The Peninsular Rivers: **Non-Perennial rivers**: Mahanadi, the Godavari, the Krishna, the Cauvery, the Narmada and the Tapi and their tributaries.

Drainage Systems Based on the Type of Drainage

The river systems of India can be classified into four groups viz.

- Himalayan rivers, Deccan rivers and Coastal rivers that drain into the sea.
- Rivers of the inland drainage basin (**endorheic basin**). Streams like the Sambhar in western Rajasthan are mainly seasonal in character, draining into the inland basins and salt lakes. In the Rann of Kutch, the only river that flows through the salt desert is the Luni.

Drainage Systems Based on Orientation to the sea

- The Bay of Bengal drainage (Rivers that drain into Bay of Bengal)(East flowing rivers)
- Arabian sea drainage (Rivers that drain into Arabian sea)(West flowing rivers).
- The rivers Narmada (India's holiest river) and Tapti flow almost parallel to each other but empty themselves in opposite directions (West flowing). The two rivers make the valley rich in alluvial soil and **teak forests** cover much of the land.

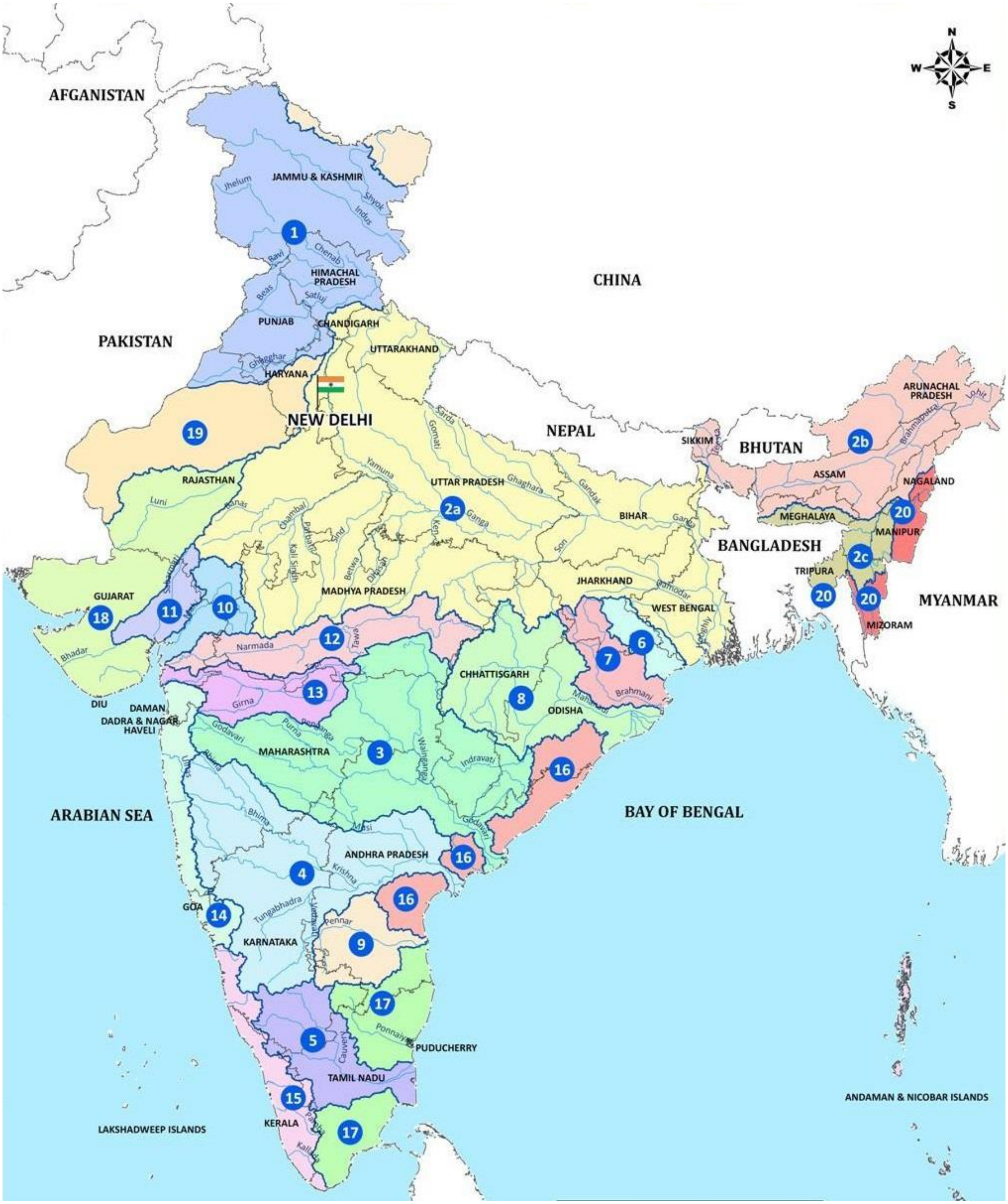
The Bay of Bengal drainage	Arabian Sea drainage
Rivers that drain into Bay of Bengal	Rivers that drain into Arabian sea
East flowing rivers	West flowing rivers
~ 77 per cent of the drainage area of the country is oriented towards the Bay of Bengal	~ 23 per cent of the drainage area of the country is oriented towards the Arabian sea
The Ganga, the Brahmaputra, the Mahanadi, the Godavari, the Krishna, the Cauvery, the Penneru, the Penneiyar, the Vaigai, etc.	The Indus, the **Narmada**, the **Tapi**, the **Sabarmati**, the **Mahi** and the large number of swift flowing western coast rivers descending from the Sahyadris.

- The area covered by The Bay of Bengal drainage and Arabian Sea drainage are not proportional to the amount of water that drains trough them.

Over 90 per cent of the water drains into the Bay of Bengal; the rest is drained into the Arabian Sea or forms inland drainage.

Lop sided distribution

- The Arabian Sea drainage or Western drainage receive less rainfall [Rajasthan, Haryana and Punjab receive very low rainfall].
- The Eastern drainage or the Bay of Bengal drainage receives rainfall both from South-west and North-east monsoons.
- Most of the Himalayan waters (perennial rivers) flow into eastern drainage (Ganges and Brahmaputra).
- Indian Rivers that flow into Arabian Sea are seasonal or non-perennial (Luni, Narmada, etc.).
- Occurrence of more cyclonic rainfall in the eastern parts is another major reason.


AFGANISTAN
PAKISTAN
CHINA
NEPAL
BHUTAN
BANGLADESH
MYANMAR
JAMMU & KASHMIR
HIMACHAL PRADESH
PUNJAB
CHANDIGARH
UTTARAKHAND
HARYANA
NEW DELHI
RAJASTHAN
UTTAR PRADESH
BIHAR
SIKKIM
ARUNACHAL PRADESH
ASSAM
NAGALAND
MEGHALAYA
MANIPUR
TRIPURA
MIZORAM
JHARKHAND
WEST BENGAL
GUJARAT
MADHYA PRADESH
CHHATTISGARH
ODISHA
DIU
DAMAN
DADRA & NAGAR HAVELI
MAHARASHTRA
ANDHRA PRADESH
GOA
KARNATAKA
PUDUCHERRY
TAMIL NADU
KERALA
ARABIAN SEA
BAY OF BENGAL
LAKSHADWEEP ISLANDS
ANDAMAN & NICOBAR ISLANDS
Jhelum
Shyok
Indus
Chenab
Ravi
Beas
Satluj
Ghaggar
Sarda
Gomati
Yamuna
Ghaghara
Gandak
Ganga
Luni
Banas
Chambal
Parbati
Kali Sindh
Sind
Betwa
Dhasan
Ken
Son
Damodar
Narmada
Tawa
Bhadar
Girna
Purna
Penganga
Godavari
Wainganga
Indravati
Mahanadi
Brahmani
Brahmaputra
Lohit
Bhima
Krishna
Tungabhadra
Pennar
Ponnaiyar
Cauvery
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Sl. No	Basin Code	Basin Name	Area (sq.km)
1	B1	Indus (Up to border)	321289
2	B2a	Ganga	861452
3	B2b	Brahmaputra	194413
4	B2c	Barak and others	41723
5	B3	Godavari	312812
6	B4	Krishna	258948
7	B5	Cauvery	81155
8	B6	Pennar	55213
9	B7	East flowing rivers between Mahanadi and Pennar	86643
10	B8	East flowing rivers between Pennar and Kanyakumari	100139
11	B9	Mahanadi	141589
12	B10	Brahmani and Baitarni	51822
13	B11	Subernarekha	29196
14	B12	Sabarmati	21674
15	B13	Mahi	34842
16	B14	West flowing rivers of Kutch and Saurashtra including Luni	321851
17	B15	Narmada	98796
18	B16	Tapi	65145
19	B17	West flowing rivers from Tapi to Tadri	55940
20	B18	West flowing rivers from Tadri to Kanyakumari	56177
21	B19	Area of inland drainage in Rajasthan	
22	B20	Minor rivers draining into Myanmar & Bangladesh	36202

Major River System or Drainage Systems in India

Himalayan River systems

- Indus River System
- Brahmaputra River System
- Ganga River System

Peninsular River Systems

- Godavari River System
- Krishna River System
- Cauvery River System
- Mahanadi River System

West Flowing Peninsular River Systems

- Narmada River System
- Tapti River System

Himalayan River Systems

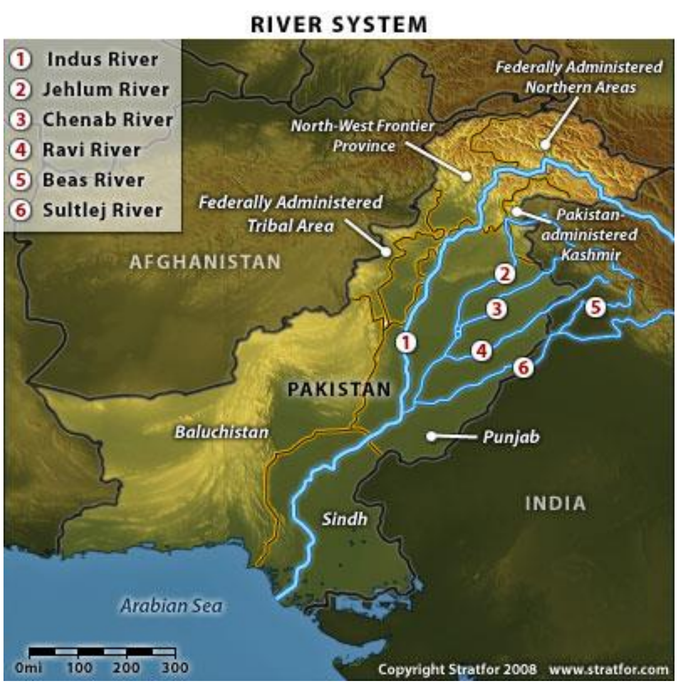
- The Indus, the Ganga and the Brahmaputra comprise the Himalayan river systems.
- The Himalayan Rivers existed even before the formation of Himalayas i.e. before the **collision of Indian Plate with the Eurasian plate**. {Antecedent Drainage}
- They were flowing into the **Tethys Sea.** These rivers had their source in the now **Tibetan region.**

- The **deep gorges** of the Indus, the Satluj, the Brahmaputra etc. clearly indicate that these rivers are **older than the Himalayas**.
- They continued to flow throughout the building phase of the Himalayas; their banks rising steeply while the beds went lower and lower due to vertical erosion (Vertical down cutting was significant and was occurring at a rate faster than the rising of Himalayas), thus cutting deep gorges.
- Thus, many of the Himalayan Rivers are typical examples of **antecedent drainage**.

Indus River System

Sindhu	**Sanskrit**
Sinthos	**Greek**
Sindus	**Latin**

Major Rivers of Indus River System	**Source**	**Length**
Indus	Glaciers of Kailas Range (Close to Manasarovar Lake)	2880 km total. 710 km in India
Jhelum	Verinag	720 km
Chenab	Bara Lacha Pass	1180 km
Ravi	Near Rohtang Pass	725 km
Beas	Near Rohtang Pass	460 km
Satluj	Manasarovar-Rakas Lakes **List of important passes given in previous posts**	1450 km total 1050 km in India



Indus River

- India got her name from Indus.
- 'The Indus Valley Civilization' was born around this river.
- It flows in north-west direction from its source **(Glaciers of Kailas Range –** Kailash range in Tibet near Lake Manasarovar**)** till the **Nanga Parbhat** Range.
- It's length is about 2,900 km. Its total drainage area is about 1,165,000 square km [more than half of it lies in semiarid plains of Pakistan]. It is joined by **Dhar River** near Indo-China border.
- After entering J&K it flows between the **Ladakh** and the **Zaskar Ranges**. It flows through the regions of Ladakh, Baltistan and Gilgit.
- The **gradient of the river in J&K is very gentle** (about 30 cm per km).
- Average elevation at which the Indus flows through JK is about **4000 m** above sea level.
- It is joined by the **Zaskar River at Leh** (these kind of points are important for prelims).
- Near **Skardu**, it is joined by the **Shyok** at an elevation of about 2,700 m.
- The **Gilgit, Gartang, Dras, Shiger, Hunza** are the other Himalayan tributaries of the Indus.
- It crosses the Himalayas (ends its mountainous journey) through a 5181 m deep gorge near **Attock**, lying north of the **Nanga Parbat.** It takes a sharp southerly bend here **(syntaxial bend).**
- **Kabul river** from Afghanistan joins Indus near **Attock.** Thereafter it flows through the **Potwar plateau** and crosses the **Salt Range** (South Eastern edge of Potwar Plateau).
- Some of the important tributaries below Attock include the **Kurram, Toch** and the **Zhob-Gomal.**
- Just above **Mithankot**, the Indus receives from **Panjnad (Panchnad)**, the accumulated waters of the five eastern tributaries—the **Jhelum, the Chenab, the Ravi, the Beas and the Satluj.**
- The river empties into the Arabian Sea south of **Karachi** after forming a huge delta.

Major Tributaries of Indus River

Jhelum River

- The Jhelum has its source in a **spring at Verinag** in the south-eastern part of the **Kashmir Valley.**
- It flows northwards into **Wular Lake** (north-western part of Kashmir Valley). From Wular Lake, it changes its course southwards. At **Baramulla** the river enters a gorge in the hills.
- The river forms steep-sided narrow gorge through **Pir Panjal Range** below **Baramula**.
- At **Muzaffarabad**, the river takes a sharp hairpin bend southward.
- Thereafter, it forms the India-Pakistan boundary for 170 km and emerges at the Potwar Plateau near Mirpur.
- After flowing through the spurs of the Salt Range it **debouches (emerge from a confined space into a wide, open area)** on the plains near the city of Jhelum.
- It joins the Chenab at **Trimmu.**
- The river is **navigable for about 160 km** out of a total length of 724 km.

Chenab River

- The Chenab originates from near the **Bara Lacha Pass** in the **Lahul-Spiti** part of the **Zaskar Range.**
- Two small streams on opposite sides of the pass, namely **Chandra** and **Bhaga**, form its headwaters at an altitude of 4,900 m.
- The united stream **Chandrabhaga** flows in the north-west direction through the **Pangi valley**, parallel to the Pir Panjal range.
- Near **Kistwar**, it cuts a deep gorge.
- It enters the plain area near **Akhnur** in Jammu and Kashmir.
- From here it through the plains of Pakistani Punjab to reach Panchnad where it joins the **Satluj** after receiving the waters of Jhelum and Ravi rivers.

Ravi River

- The Ravi has its source in **Kullu hills** near the **Rohtang Pass** in Himachal Pradesh.
- It drains the area between the **Pir Panjal** and the **Dhaola Dhar ranges**.
- After crossing Chamba, it takes a south-westerly turn and cuts a deep gorge in the Dhaola Dhar range.
- It enters Punjab Plains near **Madhopur** and later enters Pakistan below Amritsar.
- It debouches into the Chenab a little above **Rangpur in Pakistani Punjab**.

Beas River

- The Beas originates near the **Rohtang Pass**, at a height of 4,062 m above sea level, on the **southern end of the Pir Panjal Range, close to the source of the Ravi.**
- It crosses the Dhaola Dhar range and it takes a south-westerly direction and meets the Satluj river at **Harike in Punjab.**
- It is a comparatively small river which is only 460 km long but **lies entirely within the Indian territory.**

Satluj River

- The Satluj rises from the **Manasarovar-Rakas Lakes** in western Tibet at a height of 4,570 m within 80 km of the source of the Indus.
- Like the Indus, it takes a north-westerly course upto the **Shipki La** on the Tibet-Himachal Pradesh boundary.
- It cuts deep gorges where it pierces the Great Himalaya and the other Himalayan ranges.
- Before entering the Punjab plain, it cuts a gorge in Naina Devi Dhar, where the famous **Bhakra dam** has been constructed.
- After entering the plain at Rupnagar (Ropar), it turns westwards and is joined by the **Beas at Harike.**
- From near **Ferozepur to Fazilka** it forms the boundary between India and Pakistan for nearly 120 km.
- During its onward journey it receives the collective drainage of the Ravi, Chenab and Jhelum rivers. It joins the Indus a few kilometres above **Mithankot.**
- Out of its total length of 1,450 km, it flows for 1,050 km in Indian territory.

Indus water treaty

- The waters of the Indus river system are shared by India and Pakistan according to the Indus Water Treaty signed between the two countries on **19th September, 1960.**
- According to this treaty, India can utilize only **20 per cent of its total discharge of water.**

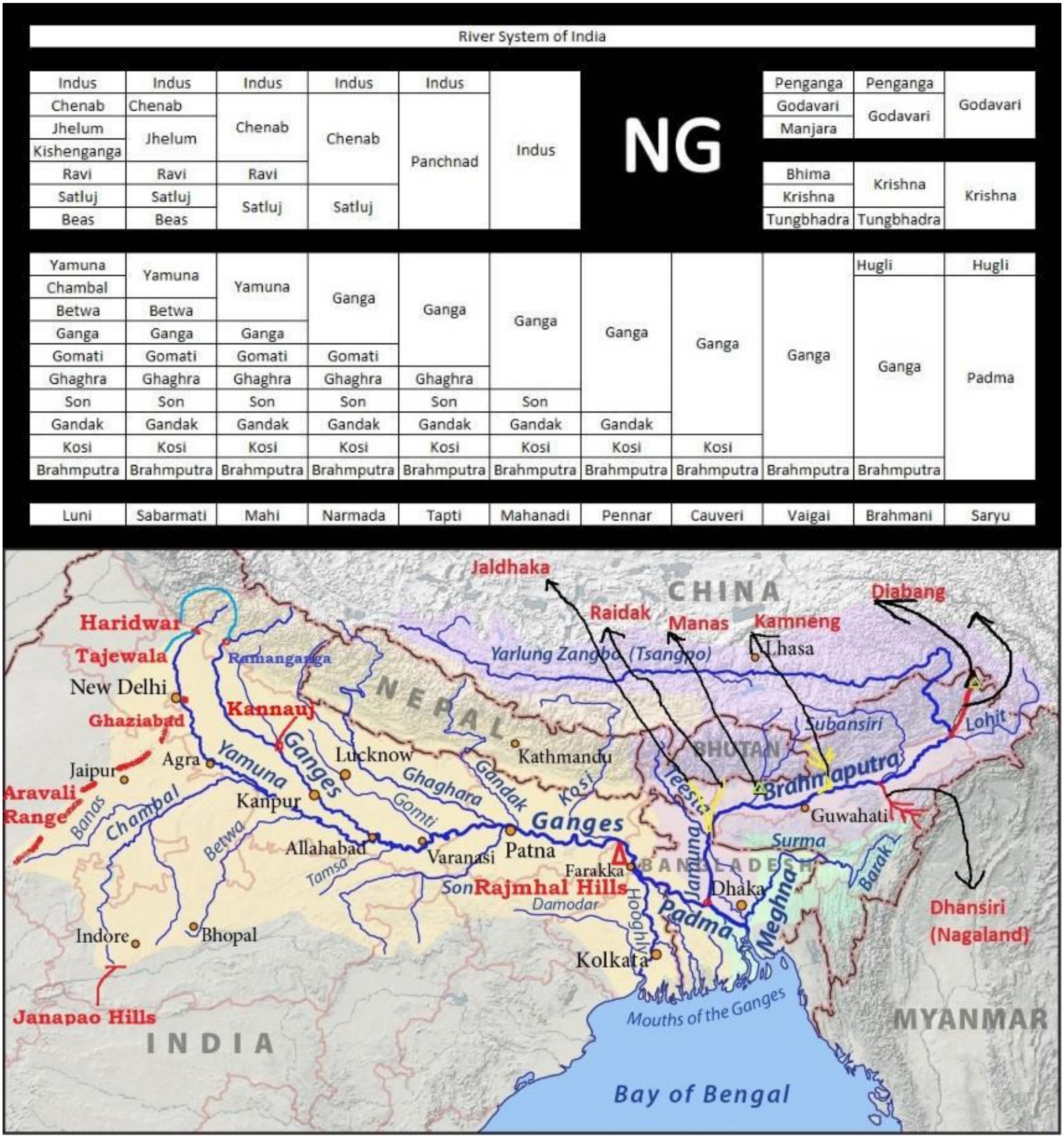
In this post: Ganga River System - Ganga River: Ganga – Brahmaputra Delta.

Right Bank Tributaries of The Ganga: Yamuna River, Chambal River, Banas River, Betwa River, Ken River, Son River, Damodar river.

Left Bank Tributaries of The Ganga River, Ramganga River, Ghaghra River, Kali River, Gandak River, Burhi Gandak, Kosi River.

Brahmaputra River System.

Ganga River System



River	**Source**
Bhagirathi (Ganga)	Gangotri glacier
Yamuna	Yamnotri glacier on the Bandarpunch Peak
Chambal	Janapao Hills in the Vindhya Range
Banas	Aravali Range
Betwa	Bhopal district

Ken	Barner Range
Son	Amarkantak Plateau
Damodar ('**Sorrow of Bengal**')	Chotanagpur plateau
Ramganga River	Garhwal district of Uttarakhand
Ghaghra River	Gurla Mandhata peak, south of Manasarovar in Tibet (river of the trans-Himalayan origin)
The Kali River (border between Nepal and Uttarakhand)	Glaciers of trans-Himalayas
Gandak River	Tibet-Nepal border
Burhi Gandak	Sumesar hills near the India-Nepal border
Kosi ('**Sorrow of Bihar**')	Tumar, Arun and Sun Kosi unite at Triveni north of the Mahabharata Range to form the Kosi.

Ganga River

- The **Ganga** originates as **Bhagirathi** from the **Gangotri glacier** in Uttar Kashi District of Uttarakhand at an elevation of 7,010 m.
- **Alaknanda** River joins **Bhagirathi** at **Devaprayag**.
- **From Devapryag the river is called as Ganga**.

The Ganges was ranked as the fifth most polluted river of the world in 2007. Pollution threatens many fish species and amphibian species and the endangered **Ganges river dolphin (Blind Dolphin)**. The Ganga Action Plan, an environmental initiative to clean up the river, has been a major

failure thus far, due to corruption, lack of technical expertise, poor environmental planning, and lack of support from religious authorities.

Major tributaries of Alaknanda	Major tributaries of Bhagirathi
East Trisul (joins Alaknanda at Karan Prayag) **Pindar** (rises from Nanda Devi) **Mandakini or Kali Ganga** (joins Alaknanda at Rudra Prayag) **Dhauliganga** **Bishenganga.** [**Kishenganga** is the tributary of Jhelum]	**Bheling**

- Ganga **debouches** [emerge from a confined space into a wide, open area] from the hills into plain area at **Haridwar.**
- It is joined by the **Yamuna** at **Allahabad**.
- Near Rajmahal Hills it turns to the south-east.
- At Farraka, it bifurcates into **Bhagirathi-Hugli in West Bengal** and **Padma-Meghna in Bangladesh** (it ceases to be known as the Ganga after Farraka).
- Brahmaputra (or the Jamuna as it is known here) joins Padma-Meghna at **Goalundo.**
- The total length of the Ganga river from its source to its mouth (measured along the Hugli) is 2,525 km.

Ganga – Brahmaputra Delta

- Before entering the Bay of Bengal, the Ganga, along with the Brahmaputra, forms the **largest delta of the world** between the **Bhagirathi/Hugli** and the **Padma/Meghna** covering an area of 58,752 sq km.
- The coastline of delta is a highly indented area.
- The delta is made of a web of distributaries and islands and is covered by dense forests called the **Sunderbans.**
- A major part of the delta is a **low-lying swamp** which is flooded by marine water during high tide.

Right Bank Tributaries of The Ganga

- Most of them **except Yamuna** originate in the peninsular region.

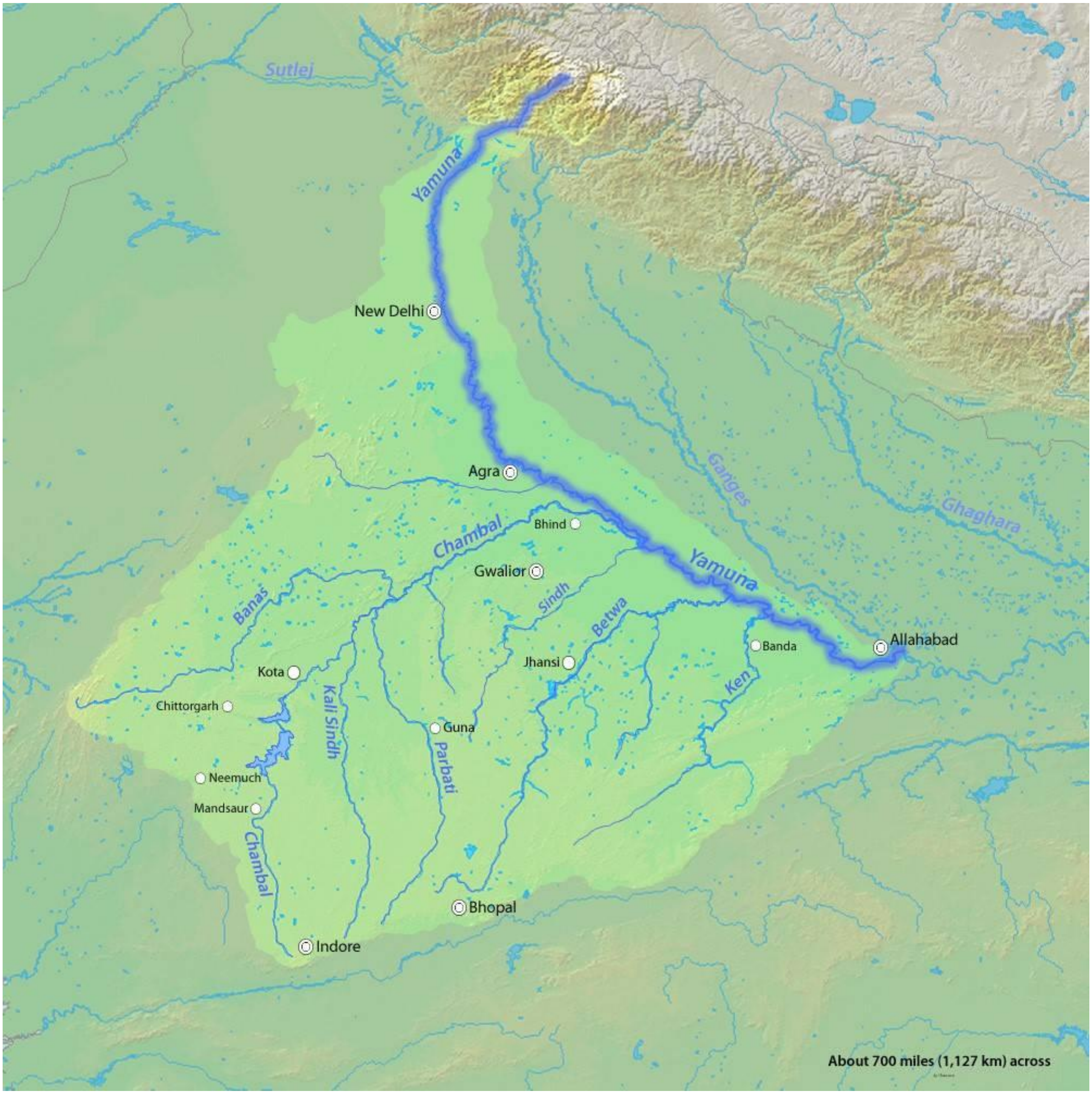
Yamuna River

- Largest and the most important tributary.
- It originates from the **Yamnotri glacier** on the **Bandarpunch Peak** in the Garhwal region in Uttarakhand at an elevation of about 6,000 meters.
- It cuts across the **Nag Tibba**, the **Mussoorie** and the Shiwalik ranges.
- It emerges out of the hilly area and enters plains near **Tajewala.**
- Its main affluent in the upper reaches is the **Tons** which also rises from the **Bandarpunch glacier**.
- It joins Yamuna below Kalsi before the latter leaves the hills.
- At this site, the water carried by the Tons is twice the water carried by the Yamuna.

Non – Peninsular Tributaries	Peninsular Tributaries
Rishiganga **Uma** **Hanuman Ganga** and **Tons** join it in the mountains. **Hindon** joins at Ghaziabad in the plain area	Most of the Peninsular rivers flow into the Yamuna between Agra and Allahabad. **Chambal** **Sind** **Betwa** **Ken.**

- It unites with the Ganga near **Triveni Sangam, Allahabad.**
- The total length of the Yamuna from its origin till Allahabad is 1,376 km.

- It creates the highly fertile alluvial, **Yamuna-Ganges Doab** region between itself and the Ganges in the Indo-Gangetic plain.



Chambal River

- The Chambal rises in the highlands of **Janapao Hills** (700 m) in the **Vindhyan Range**.
- It flows through the **Malwa Plateau.**
- It joins the Yamuna in **Etawah district** of Uttar Pradesh.
- The river flows much below its banks due to severe erosion because of poor rainfall and numerous deep ravines have been formed in the Chambal Valley, giving rise to **badland topography**. {Arid Landforms}
- The total length of the river is 1,050 km.

Dams on the Chambal

- **The Gandhi Sagar dam** is the first of the four dams built on the Chambal River, located on the Rajasthan-Madhya Pradesh border.
- **The Rana Pratap Sagar** dam is a dam located 52 km downstream of Gandhi Sagar dam on across the Chambal River in Chittorgarh district in Rajasthan.
- **The Jawahar Sagar Dam** is the third dam in the series of Chambal Valley Projects, located 29 km upstream of Kota city and 26 km downstream of Rana Pratap Sagar dam.
- **The Kota Barrage** is the fourth in the series of Chambal Valley Projects, located about 0.8 km upstream of Kota City in Rajasthan.
- Water released after power generation at Gandhi Sagar dam, Rana Pratap Sagar dam and Jawahar Sagar Dams, is diverted by Kota Barrage for irrigation in Rajasthan and in Madhya Pradesh through canals.

Keoladeo National Park is supplied with water from Chambal river irrigation project.

The Banas

- The Banas is a tributary of the Chambal.
- It originates in the southern part of the **Aravali Range.**
- It join the Chambal on **Rajasthan – Madhya Pradesh border** near **Sawai Madhopur**.

The Sind

- The Sind originates in **Vidisha Plateau** of Madhya Pradesh.
- It flows for a distance of 415 km before it joins the Yamuna.

The Betwa

- The Betwa rises in **Bhopal district (Vindhyan Range)** and joins the Yamuna near **Hamirpur.**
- It has a total length of 590 km.
- **The Dhasan** is its important tributary.

The Ken

- The Ken river rising from the **Barner Range** of Madhya Pradesh joins the Yamuna near Chila.

The Son

- The Son River rises in the **Amarkantak Plateau.**
- Its source is close to the origin of the Narmada.
- It passes along the **Kaimur Range.**
- It joins the Ganga near Danapur in Patna district of Bihar.
- It flows for a distance of 784 km from its source.
- The important tributaries of the Son are the Johilla, the Gopat, the Rihand, the Kanhar and the North Koel. Almost all the tributaries **join it on its right bank.**

Damodar river

- The Damodar river rises in the hills of the **Chotanagpur plateau** and **flows through a rift valley.**
- Rich in mineral resources, the valley is home to large-scale mining and industrial activity.
- It has a number of tributaries and subtributaries, such as **Barakar, Konar, Bokaro, Haharo, etc.**
- The **Barakar** is the most important tributary of the Damodar.
- Several dams have been constructed in the valley, for the generation of hydroelectric power. The valley is called **"the Ruhr of India".**
- The first dam was built across the Barakar River, a tributary of the Damodar river.
- It used to cause devastating floods as a result of which it earned the name **'Sorrow of Bengal'.** Now the river is tamed by constructing numerous dams.
- It joins the **Hugli River** 48 km below Kolkata.
- The total length of the river is 541 km.

Left Bank Tributaries of The Ganga River

- These rivers originate in the Himalayas.

- The major tributaries apart from the Yamuna, are **the Ramganga, the Gomati, the Ghaghra, the Gandak, the Burhi Gandak, the Bagmati, and the Kosi.**

Ramganga River

- The Ramganga river rises in the **Garhwal** district of Uttarakhand.
- It enters the Ganga Plain near Kalagarh.
- It joins the Ganga at **Kannauj.**
- The Khoh, the Gangan, the Aril, the Kosi, and the Deoha (Gorra) are important tributaries of Ramganga.

Ghaghra River

- Its source is near **Gurla Mandhata peak, south of Manasarovar in Tibet (river of the trans-Himalayan origin).**
- It is known as the **Karnaili** in Western Nepal.
- Its important tributaries are the **Sarda, the Sarju (Ayodhya is located on its bank) and the Rapti.**
- The Ghaghara joins the Ganga a few kilometres downstream of Chhapra in Bihar.
- After reaching the plain area, its stream gets divided into many branches of which, Koriyab and Garwa are important.
- The river bed is sandy and sudden bends start occurring in the stream.
- The river has a high flood frequency and has shifted its course several times.

Kali River

- Rises in the high glaciers of **trans-Himalaya.**
- It forms the boundary between **Nepal and Kumaon.**
- It is known as the **Sarda** after it reaches the plains near Tanakpur.
- It joins the **Ghaghara.**

Gandak River

- Originates near the Tibet-Nepal border at a height of 7,620 m
- It receives a large number of tributaries in Nepal Himalaya.
- Its important tributaries are the **Kali Gandak, the Mayangadi, the Bari and the Trishuli.**
- It debouches into the plains at **Tribeni.**
- It flows into Ganga at **Hajipur in Bihar**.

Burhi Gandak

- Originates from the western slopes of **Sumesar hills near the India-Nepal border**.
- It joins the Ganga near Monghyr town.

Kosi River

- The Kosi river consists of seven streams namely **Sut Kosi, Tamba Kosi, Talkha, Doodh Kosi, Botia Kosi, Arun and Tamber** and is popularly known as **Saptkaushiki.**
- These streams flow through **eastern Nepal** which is known as the **Sapt Kaushik region.**
- The sources of seven streams of the Kosi are located in snow covered areas which also receive heavy rainfall.
- Consequently, huge volume of water flows with tremendous speed.
- Seven streams mingle with each other to form three streams named the Tumar, Arun and Sun Kosi.
- They unite at **Triveni** north of the **Mahabharata Range** to form the Kosi.
- The river enters the Tarai of Nepal after cutting a narrow gorge in the Mahabharata Range.
- The joins the Ganga near **Kursela.**
- Soon after debouching onto the plain the river becomes sluggish.
- Large scale deposition of eroded material takes place in the plain region.
- The river channel is braided and it shifts its course frequently. This has resulted in frequent devastating floods and has converted large tracts of cultivable land into waste land in Bihar. Thus the river is often termed as the **'Sorrow of Bihar'.**

- In order to tame this river, a barrage was constructed in 1965 near Hanuman Nagar in Nepal.
- Embankments for flood control have been constructed as a joint venture of India and Nepal.

Brahmaputra River System

Region	Name
Tibet	Tsangpo (meaning 'The Purifier')
China	Yarlung Zangbo Jiangin
Assam Valley	Dihang or Siong, South of Sadiya: Brahmaputra
Bangladesh	Jamuna River
	Padma River: Combined Waters of Ganga and Brahmaputra
	Meghana: From the confluence of Padma and Meghna [View image above]

- The Brahmaputra (meaning the son of Brahma).
- It is 2,900 km in length.
- Source: **Chemayungdung glacier (Kailas Range)** at an elevation of about 5,150 m. It's source is very close to the sources of Indus and Satluj.
- **Mariam La** separates the source of the Brahmaputra from the Manasarovar Lake.
- Brahmaputra flows eastwards in Southern Tibet for about 1,800 km.
- In Tibet it passes through the **depression formed by the Indus-Tsangpo Structure Zone** between the Great Himalayas in the south and the Kailas Range in the north.
- Inspite of the exceptionally high altitude, the Tsangpo has a **gentle slope.** The river is sluggish and has a wide navigable channel for about 640 km.
- It receives a large number of tributaries in Tibet. The first major tributary is the **Raga Tsangpo** meeting the Tsangpo near **Lhatse Dzong**.
- The river **Ngangchu** flows through the trade centre of **Gyantse** in the south and joins the main river.
- Towards the end of its journey in Tibet, its course abruptly takes a south ward turn around **Namcha Barwa (7,756 m)(Syntaxial Bend).**
- Here it cuts across the eastern Himalaya through the **Dihang or Siang Gorge** and emerges from the mountains near **Sadiya** in the Assam Valley.
- Here it first flows under the name of **Siong and then as the Dihang**.
- In the north-eastern parts of Assam Valley, it is joined by two important tributaries viz, the **Dibang (or Sikang)** from the north and **Lohit from the south**.
- From Sadiya (Assam Valley) onwards, this mighty river is known as the **Brahmaputra.**
- The main streams merging with the Brahmaputra from the north are, Subansiri, Kameng, Dhansiri (north), Raidak, Tista etc..
- The Tista was a tributary of the Ganga prior to the floods of 1787 after which it diverted its course eastwards to join the Brahmaputra.
- The Brahmaputra has a **braided channel** (flow into shallow interconnected channels divided by deposited earth) for most of its passage through Assam where channels keep shifting. It carries a lot of silt and there is **excessive meandering.**
- The river is nearly 16 km wide at Dibrugarh and forms many islands, the most important of which is **MAJULI.** It is 90 km long and measures 20 km at its widest.
- With rainfall concentrated during the monsoon months only the river has to carry enormous quantities of water and silt which results in disastrous floods. The Brahmaputra is thus truly a **River of Sorrow**.
- The river is navigable for a distance of 1,384 km upto Dibrugarh from its mouth and serves as an excellent inland water transport route.

- Brahmaputra bends southwards and enters Bangladesh near Dhubri.
- It flows for a distance of 270 km in the name of **Jamuna river** and joins the Ganga at **Goalundo.**
- The united stream of the Jamuna and the Ganga flows further in the name of **Padma.**
- About 105 km further downstream, the Padma is joined on the left bank by the **Meghna**, originating in the mountainous region of Assam.
- From the confluence of Padma and Meghna, the combined river is known as the **Meghna** which makes a very broad estuary before pouring into the Bay of Bengal.

In this post: Peninsular River System or Peninsular Drainage – Evolution of the Peninsular Drainage, Peninsular River Systems, Himalayan River System vs. Peninsular River System.

Peninsular River System or Peninsular Drainage

- Peninsula rivers are much **older** than the Himalayan rivers {Discordant}.
- The peninsular drainage is mainly Concordant except for few rivers in the upper peninsular region.
- They are **non-perennial** rivers with a maximum discharge in the rainy season.
- The peninsular rivers have reached **mature stage** {Fluvial Landforms} and have almost reached their base level. **[Vertical downcutting is negligible].**
- The rivers are characterized by **broad and shallow valleys.**
- The river banks have gentle slopes except for a limited tract where faulting forms steep sides.
- The main **water divide** in peninsular rivers is formed by the Western Ghats, which run from north to south close to the western coast.
- The velocity of water in the rivers and the **load carrying capacity of the streams is low** due to low gradient.
- Most of the major rivers of the peninsula such as the Mahanadi, the Godavari, the Krishna and the Cauvery flow eastwards and drain into the Bay of Bengal. These rivers make **deltas at their mouths.**
- But the west flowing rivers of Narmada and Tapi as well as those originating from the Western Ghats and falling in the Arabian Sea form **estuaries in place of deltas**.
- There are few places where rivers form superimposed and rejuvenated drainage which are represented by **waterfalls.**
- Examples: The **Jog on the Sharvati** (289 m), **Yenna of Mahabaleshwar** (183 m), **Sivasamundram on the Cauvery** (101 m), **Gokak on the Gokak** (55 m), **Kapildhara** (23 m) and **Dhuandar** (15 m) on the Narmada are the major waterfalls in the Peninsular India.

Evolution of the Peninsular Drainage

Theory 1

- Geologists believe that the **Sahyadri-Aravali axis** was the main water divide in the past.
- According to one hypothesis, the existing peninsula is the remaining half of bigger landmass.
- The Western Ghats were located in the middle of this landmass.
- So one drainage was towards east flowing into Bay of Bengal and the other towards west draining into Arabian Sea.
- The western part of the Peninsula cracked and submerged in the Arabian Sea during the early **Tertiary period (coinciding with the formation of Himalayas).**
- During the collision of the Indian plate, the Peninsular block was subjected to subsidence in few regions creating a series of **rifts (trough, faults).**

The now west flowing rivers of the Peninsula, namely the Narmada and the Tapi flow through these rifts.

- Straight coastline, steep western slope of the Western Ghats, and the **absence of**

delta formations on the western coast makes this theory a possibility.

Theory 2

- It is believed that the west flowing peninsular rivers do not flow in the valleys formed by the rivers themselves.
- Rather they have occupied two fault rifts in rocks running parallel to the Vindhyas.
- These faults are supposed to be **caused by bend of the northern part of the Peninsula at the time of upheaval of the Himalayas.**
- Peninsular block, south of the cracks, tilted slightly eastwards during the event thus giving the orientation to the entire drainage towards the Bay of Bengal.
- Criticism: Tilting should have increased the gradient of the river valleys and caused some **rejuvenation** of the rivers. This type of phenomenon is absent in the Peninsula, barring a few exceptions such as waterfalls.

Peninsular River Systems

- **Rivers that drain into Bay of Bengal: The Mahanadi, the Godavari, the Krishna, the Cauvery** and several smaller rivers drains south-east into the Bay of Bengal.
- **Rivers that drain into Arabian Sea: The Narmada, the Tapi, the Mahi** flowing west as well as several small streams originating from the Western Ghats flow westwards into the Arabian Sea.
- **Rivers that drain into the Ganges:** Tributaries of the Ganga and the Yamuna such as the Chambal, the Betwa, the Ken, the Son and the Damodar flow in the north-easterly direction.

Himalayan River System vs. Peninsular River System

	The Himalayan River System	The Peninsular River System
	These rivets originate from the lofty Himalayan ranges and are named as the Himalayan rivers.	These rivers originate in the Peninsular Plateau and are named as Peninsular rivers.
Catchment area	These rivers have **large** basins and catchment areas. The total basin area of the Indus, the Ganga and the Brahmaputra is 11.78, 8.61 and 5.8 lakh square kilometres respectively.	These rivers have **small** basins and catchment areas. The Godavari has the largest basin area of 3.12 lakh square kilometres only which is less than one-third the basin area of the Indus.
Valleys	The Himalayan rivers flow through deep **V - shaped valleys** called gorges. These gorges have been carved out by down cutting carried on side by side with the uplift of the Himalayas.	The Peninsular rivers flow in comparatively **shallow valleys**. These are more or less completely graded valleys. The rivers have little erosional activity to perform.
Drainage Type	These are examples of **antecedent drainage.**	These are examples of **consequent drainage**.
Water Flow	The Himalayan rivers are **perennial** in nature, i.e., water flows throughout the year in these rivers. These rivers receive water both from the monsoons and snow-melt. The	The Peninsular rivers receive water only from rainfall and water flows in these rivers in rainy season only. Therefore, these rivers are seasonal or **non-perennial**. As such these rivers

	perennial nature of these rivers makes them useful for irrigation.	are much less useful for irrigation.
Stage	These rivers flow across the young fold mountains and are still in a **youthful** stage.	These rivers have been flowing in one of the oldest plateaus of the world and have reached **maturity.**
Meanders	The upper reaches of the Himalayan rivers are highly tortuous. When they enter the plains, there is a sudden reduction in the speed of flow of water. Under these circumstances these rivers **form meanders** and often shift their beds.	The hard rock surface and non-alluvial character of the plateau permits **little scope for the formation of meanders**. As such, the rivers of the Peninsular Plateau follow more or less **straight courses**.
Deltas and Estuaries	The Himalayan rivers form **big deltas** at their mouths. The Ganga-Brahmaputra delta is the largest in the world.	Some of the Peninsular rivers, such as the **Narmada** and the **Tapi** form **estuaries**. Other rivers such as the Mahanadi, the Godavari, the Krishna and the Cauvery form **deltas.** Several small streams originating from the Western Ghats and flowing towards the west enter the Arabian Sea without forming any delta.

In this post: East Flowing Peninsular Rivers: Godavari – Krishna – Mahanadi. Rivers, Tributaries and River Basins.

East Flowing Peninsular Rivers

- **Mahanadi River**
- **Godavari River**
- **Krishna River**
- **Kaveri (Cauvery) River**
- **Pennar River**
- **Subarnarekha River**
- **Brahamani River**
- **Sarada River**
- **Ponnaiyar River**
- **Vaigai River**

Mahanadi River

- The Mahanadi basin extends over states of Chhattisgarh and Odisha and comparatively smaller portions of Jharkhand, Maharashtra and Madhya Pradesh, draining an area of 1.4 lakh Sq.km.
- It is bounded by the Central India hills on the north, by the Eastern Ghats on the south and east and by the **Maikala range** on the west.
- The **Mahanadi ("Great River")** follows a total course of 560 miles (900 km).
- It has its source in the northern foothills of **Dandakaranya in Raipur District** of Chhattisgarh at an elevation of 442 m.
- The Mahanadi is one of the major rivers of the peninsular rivers, in water potential and **flood producing capacity**, it ranks second to the Godavari.
- Other small streams between the Mahanadi and the Rushikulya draining directly into the **Chilka Lake** also forms the part of the basin.
- The major part of basin is covered with agricultural land accounting to 54.27% of the total area.

- It is one of the **most-active silt-depositing** streams in the Indian subcontinent.
- After receiving the **Seonath River**, it turns east and enters Odisha state.
- At Sambalpur the ***Hirakud Dam*** (one of the largest dams in India) on the river has formed a man-made lake 35 miles (55 km) long.
- It enters the Odisha plains near Cuttack and enters the Bay of Bengal at False Point by several channels.
- **Puri**, at one of its mouths, is a famous pilgrimage site.

Tributaries of Mahanadi River

- Its upper course lies in the saucer-shaped basin called the **'Chhattisgarh Plain'.**
- This basin is surrounded by hills on the north, west and south as a result of which a large number of tributaries join the main river from these sides.
- Left bank Tributaries: The **Seonath**, the **Hasdeo**, the **Mand** and the **Ib.**
- Right bank Tributaries: The **Ong**, the **Tel** and the **Jonk.**

Projects on Mahanadi River

- Two important projects completed during pre-plan period in the basin are the **Mahanadi main canal** and **Tandula reservoir in Chhattisgarh**.
- During the plan period, the **Hirakud dam, Mahanadi delta project, Hasdeo Bango, Mahanadi Reservoir Project were completed.**

Industry in Mahanadi River Basin

- Three important urban centes in the basin are **Raipur, Durg and Cuttack**.
- Mahanadi basin, because of its **rich mineral resource** and **adequate power resource**, has a favorable industrial climate.
- The Important industries presently existing in the basin are the **Iron and**

Steel plant at Bhilai, **aluminium factories at Hirakud and Korba**, **paper mill near Cuttack** and **cement factory at Sundargarh**.

- Other industries based primarily on agricultural produce are sugar and textile mills.
- Mining of coal, iron and manganese are other industrial activities.

Floods in Mahanadi River Basin

- The basin is subject to **severe flooding** occasionally in the delta area due to inadequate carrying capacity of the channels.
- The multi-purpose **Hirakud dam** provides some amount of flood relief by storing part of flood water.
- However, the problem still persists and a lasting solution need to be evolved.

Godavari River

- The Godavari is the **largest river system of the Peninsular India** and is revered as **Dakshina Ganga.**
- The Godavari basin extends over states of Maharashtra, Andhra Pradesh, Chhattisgarh and Odisha in addition to smaller parts in Madhya Pradesh, Karnataka and Union territory of Puducherry (Yanam) having a total area of ~ 3 lakh Sq.km.
- The basin is bounded by **Satmala hills**, the **Ajanta range** and the **Mahadeo hills** on the north, by the Eastern Ghats on the south and the east and by the Western Ghats on the west.
- The Godavari River rises from **Trimbakeshwar in the Nashik district** of Maharashtra about 80 km from the Arabian Sea at an elevation of 1,067 m.
- The total length of Godavari from its origin to outfall into the Bay of Bengal is 1,465 km.

Tributaries of Godavari River

- The left bank tributaries are more in number and **larger** in size than the right bank tributaries.
- The **Manjra** (724 km) is the only important right bank tributary. It joins the Godavari after passing through the **Nizam Sagar.**
- *Left Bank Tributaries:* **Dharna, Penganga, Wainganga, Wardha, Pranahita** [conveying the combined waters of **Penganga, the Wardha and Wainganga], Pench, Kanhan, Sabari, Indravati etc.**
- *Right Bank Tributaries:* **Pravara, Mula, Manjra, Peddavagu, Maner** etc.
- Below Rajahmundry, the river divides itself into two main streams, the **Gautami Godavari** on the east and the **Vashishta Godavari** on the west and forms a large delta before it pours into the Bay of Bengal.
- The delta of the Godavari is of **lobate type** with a round bulge and many distributaries.

Mineral Resources in Godavari Basin

- The upper reaches of the Godavari drainage basin are occupied by the **Deccan Traps** containing minerals like **magnetite, epidote, biotite, zircon, chlorite** etc (metallic minerals)..
- The middle part of the basin is principally composed of **phyllites, quartzites, amphiboles and granites (rocks).**
- The downstream part of the middle basin is occupied mainly by sediments and rocks of the **Gondwana group**.
- The Gondwanas are principally detritals (waste or debris, in particular organic matter produced by decomposition or loose matter produced by erosion) with some thick **coal seams. [Singareni Coal Seam]**
- The Eastern Ghats dominate the lower part of the drainage basin and are formed mainly from the **Khondalites**.

Projects on Godavari River

- Important projects completed during the plan period are **Srirama Sagar, Godavari barrage, Upper Penganga, Jaikwadi, Upper Wainganga, Upper Indravati, Upper Wardha.**

- Among the on-going projects, the prominent ones are **Prnahita-Chevala** and **Polavaram.**

Industry in Godavari Basin

- The major urban Centers in the basin are **Nagpur, Aurangabad, Nashik, Rajhmundry.**
- **Nashik and Aurangabad** have large number of industries especially **automobile.**
- Other than this, the industries in the basin are mostly based on agricultural produce such as rice milling, cotton spinning and weaving, sugar and oil extraction.
- Cement and some small engineering industries also exist in the basin.

Floods and Droughts in Godavari Basin

- Godavari basin faces flooding problem in its lower reaches.
- The coastal areas are cyclone-prone.
- The delta areas face drainage congestion due to flat topography.
- A large portion of Maharashtra falling **(Marathwada)** in the basin is **drought prone.**

Krishna River

- The Krishna is the second largest east flowing river of the Peninsula.
- The Krishna Basin extends over Andhra Pradesh, Maharashtra and Karnataka having a total area of ~2.6 lakh Sq.km.
- It is bounded by **Balaghat range** on the north, by the Eastern Ghats on the south and the east and by the Western Ghats on the west.
- The Krishna River rises from the **Western Ghats** near **Jor village of Satara district**

of Maharashtra at an altitude of 1,337 m just north of **Mahabaleshwar.**

- The total length of river from origin to its outfall into the Bay of Bengal is 1,400 km.
- The major part of basin is covered with agricultural land accounting to 75.86% of the total area.
- The Krishna forms a large delta with a shoreline of about 120 km. The Krishna delta appears to merge with that formed by the Godavari and extends about 35 km into the sea.

Tributaries of Krishna River

- Right bank: **the Ghatprabha, the Malprabha and the Tungabhadra.**
- Left Bank: **the Bhima, the Musi and the Munneru.**
- The **Koyna** is a small tributary but is known for **Koyna Dam**. This dam was perhaps the main cause of the devastating **earthquake** (6.4 on richter scale) in 1967 that killed 150 people.
- The Bhima originates from the **Matheron Hills** and joins the Krishna near Raichur after for a distance of 861 km.
- The Tungabhadra is formed by the unification of the **Tunga** and the **Bhadra** originating from **Gangamula** in the **Central Sahyadri**. Its total length is 531 km.
- At Wazirabad, it receives its last important tributary, the **Musi**, on whose banks the city of Hyderabad is located.

Projects on Krishna River

- Important ones are the **Tungabhadra, Ghataprabha, Nagarjunasagar, Malaprabha, Bhima, Bhadra** and **Telugu Ganga.**
- The major Hydro Power stations in the basin are **Koyna, Tungabhadara, Sri Sailam, Nagarjuna Sagar, Almatti, Naryanpur, Bhadra.**
- Tunagabhadra is a major inter-States project in the basin. In order to operate the project and to regulate the flows among the beneficiary States of Karnataka and Andhara Pradesh.

Resources in Krishna Basin

- The basin has rich mineral deposits and there is good potential for industrial development.
- Iron and steel, cement, sugar cane vegetable oil extraction and rice milling are important industrial activities at present in the basin.
- Recently oil has been struck in this basin which is bound to have an effect on the future industrial scenario of this basin.

Industry in Krishna Basin

- The major Urban Centers in the Basin are **Pune, Hyderabad.**
- Hyderabad is the state capital of Telangana and is now a major IT hub.
- Pune in Maharashtra has number of **automobile and IT industry** and is major education centre.

Drought and Floods in Krishna Basin

- Some parts of the basin, especially the Rayalaseema area of Andhra Pradesh, Bellary, Raichur, Dharwar, Chitradurga, Belgaum and Bijapur districts of Karnataka and Pune, Sholapur, Osmanabad and Ahmedanagar districts of Maharashtra are **drought-prone.**
- The delta area of the basin is subject to flooding. It has been observed that the river bed in delta area is continuously raised due to silt deposition resulting in reduction in carrying capacity of the channel.
- The coastal cyclonic rainfall of high intensity and short duration makes the flood problem worse.

Cauvery River

- The Kaveri (Cauvery) is designated as the **'Dakshina Ganga'** or **'the Ganga of the South'.**
- The Cauvery River rises at an elevation of 1,341 m at **Talakaveri** on the **Brahmagiri range** near Cherangala village of **Kodagu (Coorg) district of Karnataka.**

- The total length of the river from origin to outfall is 800 km.
- The Cauvery basin extends over states of Tamil Nadu, Karnataka, Kerala and Union Territory of Puducherry draining an area of 81 thousand Sq.km.
- It is bounded by the Western Ghats on the west, by the Eastern Ghats on the east and the south and by the ridges separating it from Krishna basin and Pennar basin on the north.
- The Nilgiris, an offshore of Western ghats, extend Eastwards to the Eastern ghats and divide the basin into two natural and political regions i.e., Karnataka plateau in the North and the Tamil Nadu plateau in the South.
- Physiographically, the basin can be divided into three parts – the Westen Ghats, the Plateau of Mysore and the Delta.
- The delta area is the most fertile tract in the basin. The principal soil types found in the basin are black soils, red soils, laterites, alluvial soils, forest soils and mixed soils. **Red soils** occupy large areas in the basin. Alluvial soils are found in the delta areas.
- The basin in Karnataka receives rainfall mainly from the S-W Monsoon and partially from N-E Monsoon. The basin in Tamil Nadu receives good flows from the North-East Monsoon.
- Its upper catchment area receives rainfall during summer by the south-west monsoon and the lower catchment area during winter season by the retreating north-east monsoon.
- It is, therefore **almost a perennial river** with comparatively less fluctuations in flow and is **very useful for irrigation** and hydroelectric power generation.

- Thus the Cauvery is **one of the best regulated rivers** and 90 to 95 per cent of its irrigation and power production potential already stands harnessed.
- The river drains into the Bay of Bengal. The major part of basin is covered with agricultural land accounting to 66.21% of the total area.

Tributaries of the Cauvery River

- Left Bank: the **Harangi**, the **Hemavati**, the **Shimsha** and the **Arkavati**.
- Right Bank: **Lakshmantirtha**, the **Kabbani**, the **Suvarnavati**, the **Bhavani**, the **Noyil** and the **Amaravati** joins from right.
- The river descends from the South Karnataka Plateau to the Tamil Nadu Plains through the ***Sivasamudram waterfalls (101 m high).***
- At Shivanasamudram, the river branches off into two parts and falls through a height of 91 m. in a series of falls and rapids.
- The falls at this point is utilized for power generation by the power station at Shivanasamudram.
- The two branches of the river join after the fall and flow through a wide gorge which is known as **'Mekedatu' (Goats leap)** and continues its journey to form the boundary between Karnataka and Tamil Nadu States for a distance of 64 km.
- At **Hogennekkal Falls**, it takes Southerly direction and enters the **Mettur Reservoir.**
- A tributary called Bhavani joins Cauvery on the Right bank about 45 Kms below **Mettur Reservoir.** Thereafter it enters the plains of Tamil Nadu.
- Two more tributaries Noyil and Amaravathi join on the right bank and here the river widens with sandy bed and flows as **'Akhanda Cauvery'.**
- Immediately after crossing Tiruchirapalli district, the river divides into two parts, the Northern branch being called **'The Coleron'** and Southern branch remains as Cauvery and from here the Cauvery Delta begins.
- After flowing for about 16 Kms, the two branches join again to form '**Srirangam Island**'.
- On the Cauvery branch lies the "**Grand Anicut**" said to have been constructed by a Chola King in 1st Century A.D.
- Below the Grand Anicut, the Cauvery branch splits into two, Cauvery and **Vennar**.
- These branches divide and sub-divide into small branches and form a network all over the delta.

Floods in Cauvery Basin

- The Cauvery basin is fan shaped in Karnataka and leaf shaped in Tamil Nadu. The run-off **does not drain off quickly** because of its shape and therefore **no fast raising floods occur** in the basin.

Projects on Cauvery River

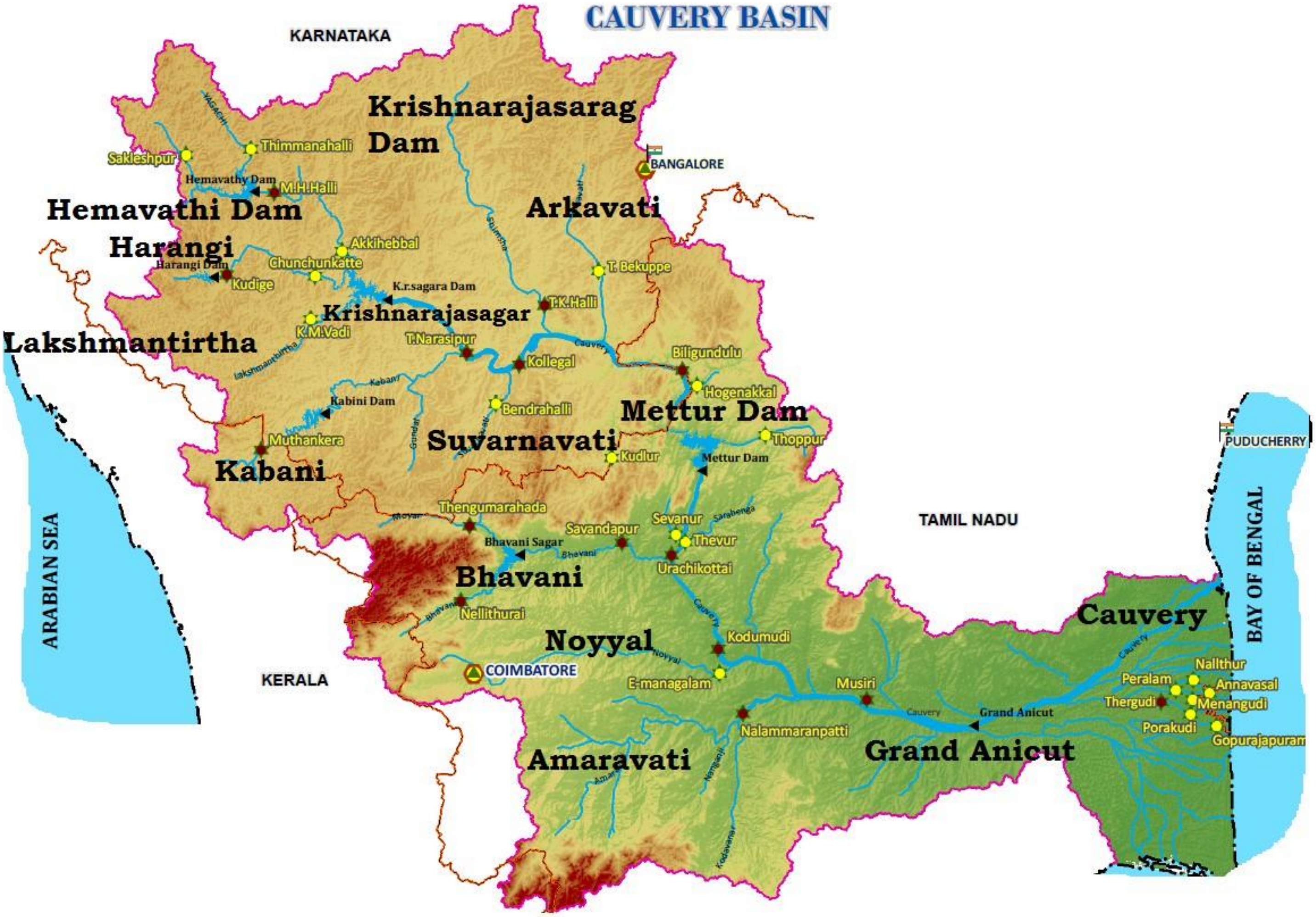
- During the pre-plan period many projects were completed in this basin which included **Krishnarajasagar** in Karnataka, **Mettur dam** and **Cauvery delta system** in Tamil Nadu.
- Lower **Bhavani, Hemavati, Harangi, Kabini** are important projects completed during the plan period.

Industry in Cauvery Basin

- The city of Bangalore is situated just outside this basin.
- Important industries in the basin include **cotton textile industry in Coimbatore** and Mysore, cement factories in Coimbatore and Trichinapally and industries based on mineral and metals.
- The **Salem steel plant** and many engineering industies in Coimbatore and Trichinapally are also situated in this basin.

Pennar River

- The Pennar (also known as **Uttara Pinakini**) is one of the major rivers of the peninsula.



- The Pennar rises in the **Chenna Kasava hill** of the **Nandidurg range**, in **Chikkaballapura district** of **Karnataka** and flows towards east eventually draining into the Bay of Bengal.
- The total length of the river from origin to its outfall in the Bay of Bengal is 597 km.
- Located in peninsular India, the Pennar basin extends over states of Andhra Pradesh and Karnataka having an area of ~55 thousand Sq.km
- The fan shaped basin is bounded by the **Erramala range** on the north, by the **Nallamala** and **Velikonda** ranges of the Eastern Ghats on the east, by the **Nandidurg hills** on the south and by the narrow ridge separating it from the Vedavati valley of the Krishna Basin on the west.
- The other hill ranges in the basin to the south of the river are the **Seshachalam [famous for Red Sanders]** and **Paliconda ranges.**
- The major part of basin is covered with agriculture accounting to 58.64% of the total area.

Tributaries of Pennar River

- Left Bank: the **Jayamangali**, the **Kunderu** and the **Sagileru.**
- Right bank: the **Chiravati**, the **Papagni** and the **Cheyyeru.**

Projects on Pennar River

- Tungabhadra high level canal in Krishna basin irrigated areas in Pennar basin also. The only major project in the basin is the **Somasila project.**

Industry in Pennar Basin

- The only important town in the basin is **Nellore.**


EAST FLOWING RIVER BASIN
PENNAR TO KANYAKUMARI
इंडिया - वारिस
India - WRIS
ANDHRA PRADESH
KARNATAKA
TAMIL NADU
KERALA
BAY OF BENGAL
SRI LANKA
CHENNAI
PUDUCHERRY
BANGLORE
COIMBATORE
TRIVANDRUM
Naidupet
Sulurpet
Arcot
Magaral
Chengalpet
Avarankuppam
Gummanur
Sathanur Dam
Vazhavachanur
Kumarapalayam
Villupuram
Manimuthar Dam
Kudalaiyathur
Vaigai Dam
Theni
Ambasamudram
Paramakudi
Irrukkankudi
A.p.puram
Murappanadu
Kandleru
Kolleru
Uppuleru
Swarnamukhi
Kalangi
Nagari
Nandi
Kottalaiyar
Kuvam
Palar
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Padavettar
Cheyar
Kaliyar
Aayar
Tandi
Vaniyar
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GDQ
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Divisional Office
Circle Office
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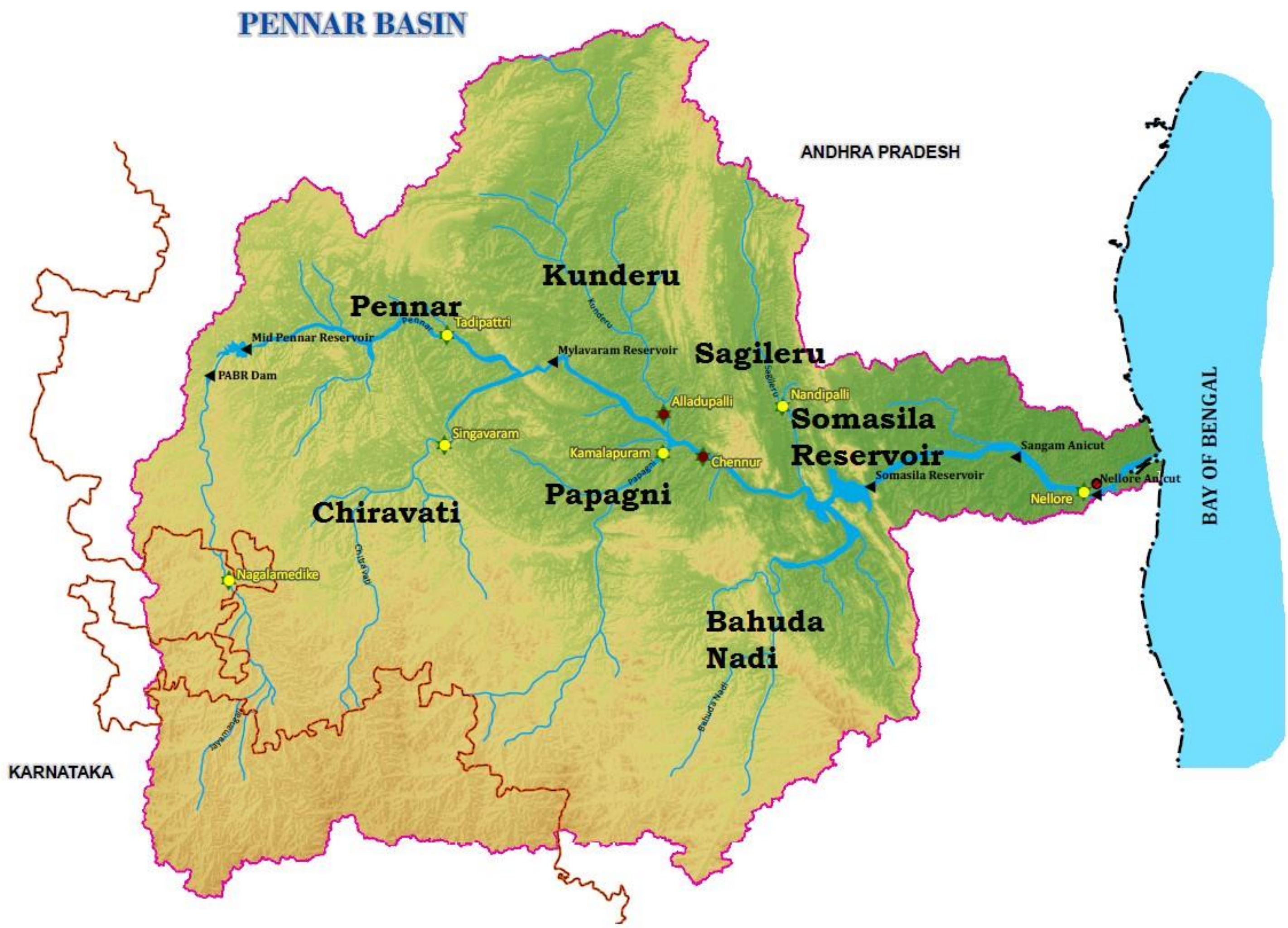
River
Basin Boundary
State Boundary
International Boundary
* All sites are not shown at this map scale
* For International/State boundaries and Coast-Line refer to Survey of India maps.



- With limited water and power potential and mineral resources, the scope for industrial development is limited in the basin.
- There are no major industries. The existing small industries are mostly based on agricultural produce such as cotton weaving, sugar mills, oil mills, rice mills etc.

Subarnarekha

- The Subarnarekha originates from the **Ranchi Plateau** in Jharkhand forming the boundary between West Bengal and Odisha in its lower course.
- It joins Bay of Bengal forming an estuary between the Ganga and Mahanadi deltas. Its total length is 395 km.

Brahamani River

- The Brahmani river comes into existence by the confluence of the **Koel** and the **Sankh rivers** near **Rourkela**. It has a total length of 800 km.
- The basin is bounded in the North by Chhotanagpur plateau, in the West and South by the Mahanadi basin and in the East by the Bay of Bengal.
- The basin flows through Jharkhand, Chhattisgarh and Orissa States and drains into Bay of Bengal.

Sarada River

- The river Sarada, an East flowing medium sized river, lies in the district of Visakhapatnam of Andhra Pradesh.

Ponnaiyar River

- The Ponnaiyar is a small stream which is confined to the coastal area only.

- It covers a small area in the state of Tamil Nadu, Karnataka and Andhra Pradesh.
- The Basin is bounded on the North -West and South by various ranges of the Eastern Ghats like the Velikonda Range, the Nagari hills, the Javadu hills, the Shevaroy hills, the Chitteri hills and the Kalrayan hills and in the East by the Bay of Bengal.

Vaigai River

- South of the Cauvery delta, there are several streams, of which the Vaigai is the longest.
- The Vaigai basin is an important basin among the 12 basins lying between the Cauvery and Kanyakumari.
- This basin is bounded by the Varushanadu hills, the Andipatti hills, the Cardaman hills and the Palani hills on the West and by the Palk strait and Palk Bay on the East.
- The Vaigai drains an area of 7,741 Sq.Km, which entirely lies in the state of Tamil Nadu.

In this post: West Flowing Rivers of The Peninsular India – Narmada – Tapti – Sabarmati – Mahi – Luni – Ghaggar River [Inland Drainage]. West flowing Rivers of the Sahyadris (Western Ghats)

West Flowing Rivers of The Peninsular India

- The west flowing rivers of the Peninsular India are fewer and smaller as compared to their east flowing counterparts.
- The two major west flowing rivers are the **Narmada** and the **Tapi.**
- This exceptional behavior is because these rivers didn't form valleys and instead they flow through faults (linear rift, rift valley, trough) created due to the bending of the northern peninsula during the formation process of Himalayas.
- These faults run parallel to the **Vindhyas** and the **Satpuras**.
- The **Sabarmati, Mahi** and **Luni** are other rivers of the Peninsular India which flow westwards.
- Hundreds of small streams originating in the **Western Ghats** flow swiftly westwards and join the Arabian Sea.
- It is interesting to note that the Peninsular rivers which fall into the Arabian Sea **do not form deltas, but only estuaries.** {Fluvial Depositional Landforms}
- This is due to the fact that the west flowing rivers, especially the Narmada and the Tapi flow through **hard rocks** and hence do not carry any good amount of silt.
- Moreover, the tributaries of these rivers are very small and hence they don't contribute any silt.
- Hence these rivers are not able to form distributaries or a delta before they enter the sea.

Estuary

- An estuary is a partially enclosed body of water along the coast where freshwater from rivers and streams meets and mixes with salt water from the ocean. [Primary productivity in estuaries is very high. Fishing is a dominant occupation around estuaries. Most of the estuaries are good **bird sanctuaries**].

- Estuaries and the lands surrounding them are places of transition from land to sea and freshwater to salt water.
- Although influenced by the tides, they are protected from the full force of ocean waves, winds, and storms by such land forms as barrier islands or peninsulas. [**You know why estuaries make good ports?**]
- Estuarine environments are among the most productive on earth, creating more organic matter each year than comparably-sized areas of forest, grassland, or agricultural land.
- The tidal, sheltered waters of estuaries also support unique communities of plants and animals especially adapted for life at the margin of the sea.
- Estuaries have important commercial value and their resources provide economic benefits for tourism, fisheries, and recreational activities.
- The protected coastal waters of estuaries also support important public infrastructure, serving as **harbors and ports** vital for shipping and transportation.
- Estuaries also perform other valuable services. Water draining from uplands carries sediments, nutrients, and other pollutants to estuaries. As the water flows through wetlands such as swamps and salt marshes, much of the sediments and pollutants are filtered out.
- Salt marsh grasses and other estuarine plants also help prevent erosion and stabilize shorelines [**Mangroves**].

Narmada River

- Narmada is the largest west flowing river of the peninsular India.
- Narmada flows westwards through a **rift valley** between the Vindhyan Range on the north and the Satpura Range on the south.
- It rises from **Maikala range near Amarkantak** in **Madhya Pradesh**, at an elevation of about 1057 m.
- Narmada basin extends over states of Madhya Pradesh, Gujarat, Maharashtra and Chhattisgarh having an area ~1 Lakh Sq.km.
- It is bounded by the Vindhyas on the north, Maikala range on the east, Satpuras on the south and by the Arabian Sea on the west.
- Its total length from its source in **Amarkantak** to its estuary in the **Gulf of Khambhat** is 1,310 km.
- The hilly regions are in the upper part of the basin, and lower middle reaches are broad and fertile areas well suited for cultivation.
- **Jabalpur** is the only important urban centre in the basin.
- The river slopes down near Jabalpur where it cascades (a small waterfall, especially one in a series) 15 m into a gorge to form the ***Dhuan Dhar (Cloud of Mist) Falls.***
- Since the gorge is composed of marble, it is popularly known as the Marble Rocks.
- It makes two waterfalls of 12 m each at Mandhar and Dardi. Near Maheshwar the river again descends from another small fall of 8 m, known as the **Sahasradhara Falls.**
- There are several islands in the estuary of the Narmada of which **Aliabet** is the largest.
- The Narmada is navigable upto 112 km from its mouth.

Tributaries of Narmada River

- Since the river flows through a narrow valley confined by precipitous (dangerously high or steep) hills, it does not have many tributaries.
- The absence of tributaries is especially noted on the right bank of the river where the **Hiran** is the only exception.
- The other right bank tributaries are the **Orsang, the Barna and the Kolar**.
- A few left bank tributaries drain the northern slopes of the Satpura Range and join the Narmada at different places.

- The major Hydro Power Project in the basin are **Indira Sagar, Sardar Sarovar, Omkareshwar, Bargi & Maheshwar.**

Tapti River

- The Tapti (also known as the Tapi) is the second largest west flowing river of the Peninsular India and is known as 'the twin' or 'the handmaid' of the Narmada.
- It originates near **Multai reserve forest in Madhya Pradesh** at an elevation of 752 m.
- Flows for about 724 km before outfalling into the Arabian Sea through the **Gulf of Cambay [Gulf of Khambhat].**
- The Tapti River along with its tributaries flows over the plains of **Vidharbha, Khandesh** and Gujarat and over large areas in the state of Maharashtra and a small area in Madhya Pradesh and Gujarat.
- The basin extends over states of Madhya Pradesh, Maharashtra and Gujarat having an area of ~ 65,000 Sq.km
- Situated in the Deccan plateau, the basin is bounded by the **Satpura range** on the north, **Mahadev hills** on the east, **Ajanta Range** and the **Satmala hills** on the south and by the Arabian Sea on the west.
- The hilly region of the basin is well forested while the plains are broad and fertile areas suitable for cultivation.
- There are two well defined physical regions, in the basin, viz hilly region and plains; the hilly regions comprising **Satpura, Satmalas, Mahadeo, Ajanta** and **Gawilgarh hills** are well forested.
- The plain covers the **Khandesh areas** (Khandesh is a region of central India, which forms the northwestern portion of Maharashtra state) which are broad and fertile suitable for cultivation primarily.

Tributaries of Tapti River

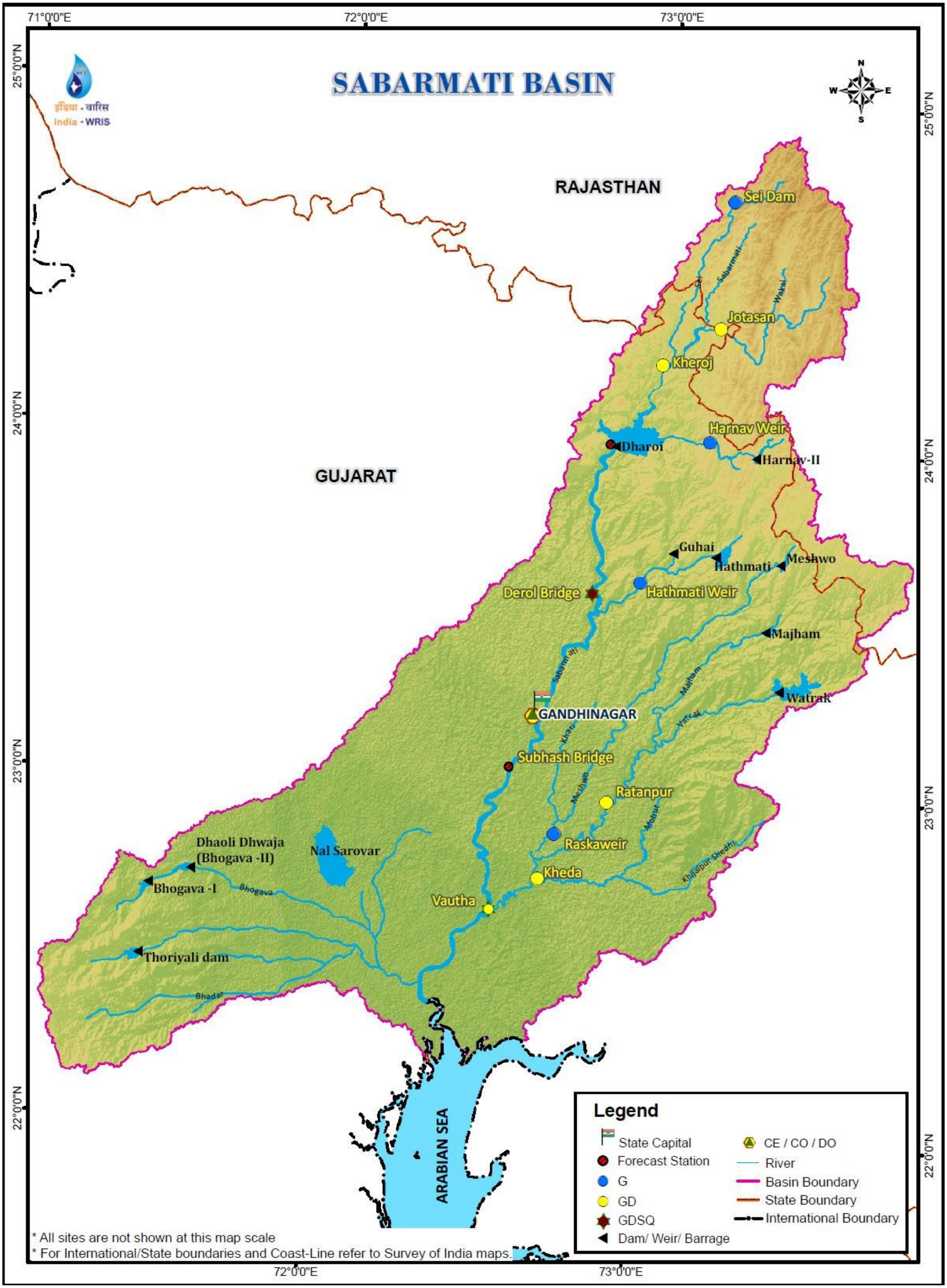
- ***Right Bank:*** the **Suki**, the **Gomai**, the **Arunavati** and the **Aner**.
- ***Left Bank:*** the **Vaghur**, the **Amravati**, the **Buray**, the **Panjhra**, the **Bori**, the **Girna**, the **Purna**, the **Mona** and the **Sipna**.

Projects on Tapti River

- Hathnur Dam of Upper Tapi Project (Maharashtra)
- Kakrapar weir and Ukai Dam of Ukai Project (Gujarat)
- Girna Dam and Dahigam Weir of Girna Project (Maharashtra)

Industry in the Tapti Basin

- Important industries in the basin are **textile factories in Surat** and **paper and news print factory at Nepanagar.**


SABARMATI BASIN
इंडिया - वारिस
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RAJASTHAN
GUJARAT
ARABIAN SEA
Sei Dam
Jotasan
Kheroj
Harnav Weir
Dharoi
Harnav-II
Guhai
Hathmati
Meshwo
Derol Bridge
Hathmati Weir
Majham
Watrak
GANDHINAGAR
Subhash Bridge
Ratanpur
Raskaweir
Kheda
Vautha
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Sabarmati
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* For International/State boundaries and Coast-Line refer to Survey of India maps.
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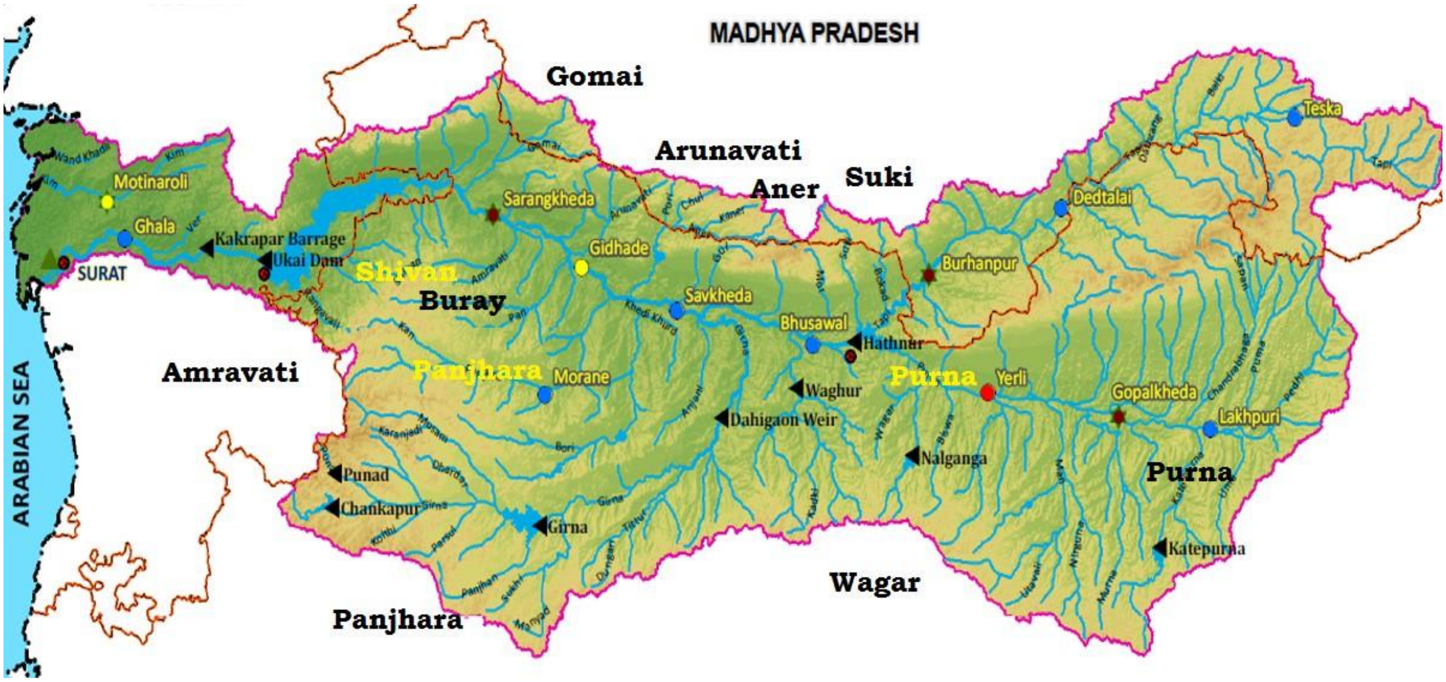


Sabarmati River

- The Sabarmati is the name given to the combined streams the **Sabar** and **Hathmati**.
- The Sabarmati basin extends over states of Rajasthan and Gujarat having an area of 21,674 Sq km.
- The basin is bounded by **Aravalli hills** on the north and north-east, by Rann of Kutch on the west and by Gulf of Khambhat on the south.
- The basin is roughly triangular in shape with the Sabarmati River as the base and the source of the **Vatrak River** as the apex point.
- Sabarmati originates from **Aravalli hills** at an elevation of 762 m near village Tepur, in **Udaipur district of Rajasthan.**
- The total length of river from origin to outfall into the Arabian Sea is 371 km.
- The major part of basin is covered with agriculture accounting to 74.68% of the total area.
- Rainfall varies from a meager few mm in Saurastra to over 1000 mm in southern part.
- Left bank tributaries: the Wakal, the Hathmati and the Vatrak.
- Right bank tributaries: the Sei.
- Projects: Sabarmati reservoir (Dharoi), Hathmati reservoir and Meshwo reservoir project are major projects completed during the plan period.

Industry in Sabarmati Basin

- **Gandhinagar** and **Ahmedabad** are the important urban centers in the basin.
- Ahmedabad is an industrial city situated on the banks of Sabarmati.
- Important industries are textiles, leather and leather goods, plastic, rubber goods, paper, newsprint, automobile, machine tools, drugs and pharmaceuticals etc.
- The industrial city of Ahmedabad poses the danger of water pollution.

Mahi River

- The Mahi basin extends over states of Madhya Pradesh, Rajasthan and Gujarat having total area of 34,842 Sq km.
- It is bounded by **Aravalli hills** on the north and the north-west, by **Malwa Plateau** on the east, by the **Vindhyas** on the south and by the Gulf of Khambhat on the west.
- Mahi is one of the major interstate west flowing rivers of India.
- It originates from the northern slopes of Vindhyas at an altitude of 500 m in **Dhar district of Madhya Pradesh.**

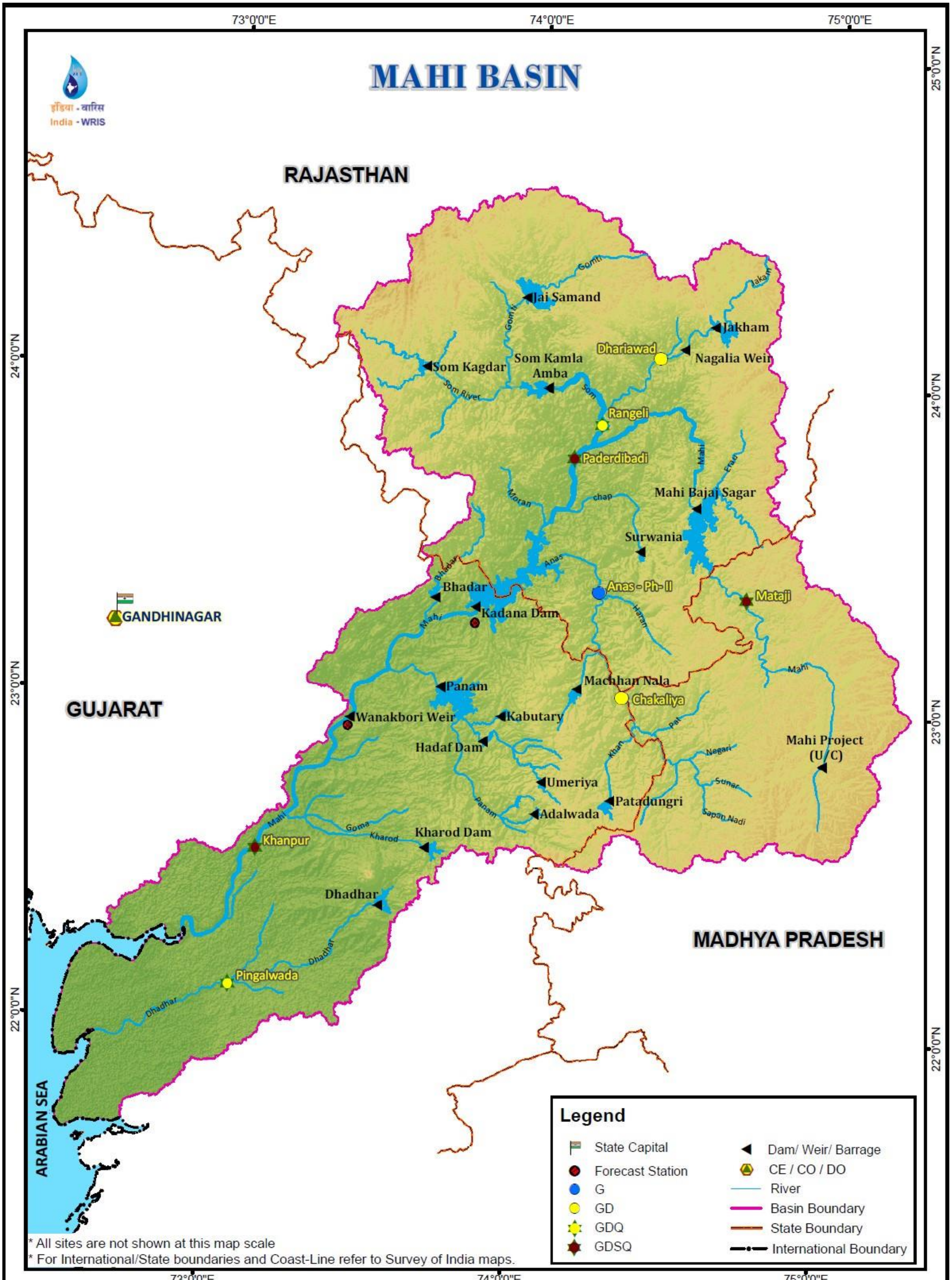
- The total length of Mahi is 583 km.
- It drains into the Arabian Sea through the Gulf of Khambhat.
- The major part of basin is covered with agricultural land accounting to 63.63% of the total area
- Hydro Power stations are located in Mahi Bajaj Sagar dam and at Kadana Dam.
- **Vadodara** is the only important urban centre in the basin. There are not many industries in the basin.
- Some of the industries are cotton textile, paper, newsprint, drugs and pharmaceuticals. Most of these industries are located at **Tatlam.**

Luni River

- The Luni or the **Salt River** (Lonari or Lavanavari in Sanskrit) is named so because its water is brackish below Balotra.
- Luni is the only river basin of any significance in Western Rajasthan, which form the bulk of arid zone.
- Luni originates from western slopes of the **Aravalli ranges** at an elevation of 772 m near **Ajmer** flowing in South West direction and traversing a course of 511 km in Rajasthan, it finally flow into the **Rann of Kachchh** (it gets lost in the marsh).
- Most of its tributaries drain the steep north west of Aravalli hills and join it on left side. Its total catchment area falls in Rajasthan.
- The peculiarity of this river is that it **tends to increase its width** rather than deepening the bed because the banks are of soils, which are easily erodible whereas beds are of sand. The floods develop and disappear so rapidly that they have no time to scour the bed.

West flowing Rivers of the Sahyadris (Western Ghats)

- About six hundred small streams originate from the Western Ghats and flow westwards to fall into the Arabian Sea.
- The western slopes of the Western Ghats receive heavy rainfall from the south-west monsoons and are able to feed such a large number of streams.
- Although only about 3% of the areal extent flow swiftly down the steep slope and some of them make waterfalls.
- The **Jog or Gersoppa Falls** (289 m) made by the **Sharavati river** is the most famous waterfall of India.



MAHI BASIN
India - WRIS
RAJASTHAN
GUJARAT
MADHYA PRADESH
ARABIAN SEA
GANDHINAGAR
Jai Samand
Jakham
Nagalia Weir
Dhariawad
Som Kagdar
Som Kamla Amba
Rangeli
Paderdibadi
Mahi Bajaj Sagar
Surwania
Bhadar
Kadana Dam
Anas - Ph- II
Mataji
Panam
Machhan Nala
Chakaliya
Wanakbori Weir
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* All sites are not shown at this map scale
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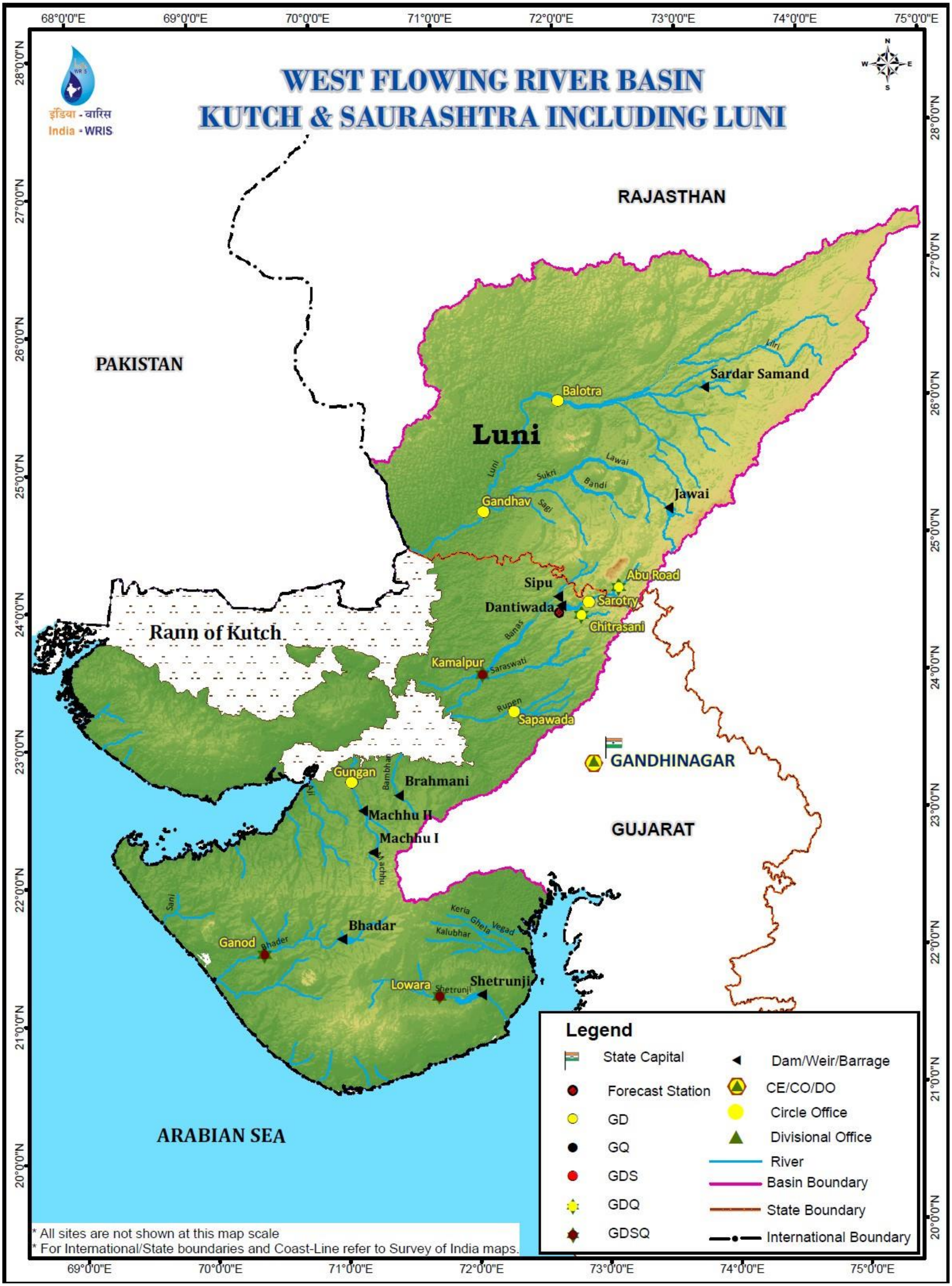
WEST FLOWING RIVER BASIN
KUTCH & SAURASHTRA INCLUDING LUNI
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RAJASTHAN
PAKISTAN
Luni
Balotra
Sardar Samand
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Jawai
Sipu
Dantiwada
Abu Road
Sarotry
Chitrasani
Rann of Kutch
Kamalpur
Sapawada
GANDHINAGAR
Gungan
Brahmani
Machhu II
Machhu I
GUJARAT
Bhadar
Ganod
Lowara
Shetrunji
ARABIAN SEA
Legend
State Capital
Forecast Station
GD
GQ
GDS
GDQ
GDSQ
Dam/Weir/Barrage
CE/CO/DO
Circle Office
Divisional Office
River
Basin Boundary
State Boundary
International Boundary
* All sites are not shown at this map scale
* For International/State boundaries and Coast-Line refer to Survey of India maps.


WEST FLOWING RIVER
TAPI TO TADRI
SURAT
Mahuwa
Jhuj
Gadat
Daman
Varai
Vapi Town
Madhuban Dam
Silvassa
Nanipalsan
Solachar
Ozerkheda
Dhamni
Upper Vaitarna
Durvesh
Lower Vaitarna (Modak Sagar)
Tansa
Bhatsa
BADLAPUR
PEN
MUMBAI
NAGTHONE
MAHARASHTRA
PUNE
MANGAON
MAHAD
ARABIAN SEA
NIVALI
ANJANARI
Arunawati
BELNE BRIDGE
Talamba
Tillari
GANJIM
PANJI
KARNATAKA
Supa
COLLEM
Saluli
GOA
Tattihalla
SANTEGULI
Legend
State Capital
Forecast Station
G
GD
GDQ
GDSQ
Dam/ Weir/ Barrage
Divisional Office
River
Basin Boundary
State Boundary
International Boundary
* All sites are not shown at this map scale
* For International/State boundaries and Coast-Line refer to Survey of India maps.

Ghaggar River – Inland Drainage

- Some rivers of India are not able to reach the sea and constitute inland drainage.
- Large parts of the **Rajasthan desert** and parts of **Aksai Chin** in **Ladakh** have inland drainage.
- The ***Ghaggar*** is the most important river of inland drainage. It is a seasonal stream which rises on the lower slopes of the Himalayas and forms boundary between **Haryana and Punjab.**

It gets lost in the dry sands of Rajasthan near Hanumangarh after traversing a distance of 465 km.

Earlier, this river was an affluent of the Indus, the dry bed of the old channel is still traceable.

Its main tributaries are the Tangri, the Markanda, the **Saraswati** and the Chaitanya.

It contains a lot more water in rainy season when its bed becomes 10 km wide at places.

Most of the streams draining western slopes of the Aravalli Range dry up immediately after they enter the sandy arid areas to the west of this range.

Usability of Rivers

Source of fresh water, irrigation, hydro-electric production, navigation etc.

The Himalayas, Vindhyas, Satpuras, Aravalis, Maikala, Chhotanagpur plateau, Meghalaya plateau, Purvachal, Western and the Eastern Ghats offer possibilities of large scale water power development.

Sixty per cent of the total river flow is concentrated in the Himalayan rivers, 16 per cent in the Central Indian rivers (the Narmada, the Tapi, the Mahanadi, etc.), and the rest in the rivers of the Deccan plateau.

The Ganga and the Brahmaputra in the north and northeastern part of the country, the Mahanadi in Odisha, the Godavari and the Krishna in Andhra and Telangana the Narmada and the Tapi in Gujarat, and the lakes and tidal creeks in coastal states possess some of the important and useful waterways of the country.

- In the past they were of great importance, which suffered a great deal with the advent of **rail and roads**.

- Withdrawal of large quantities of water for irrigation resulted in dwindling flow of many rivers.
- The most important navigable risers are the Ganga, the Brahmaputra and the Mahanadi. The Godavari, the Krishna, the Narmada and the Tapi are navigable near their mouths only.

Indian Monsoons – Factors responsible for south-west monsoon and north-east monsoon formation. Mechanism of Indian Monsoons. Indian Monsoons – ITCZ [Inter-Tropical Convergence Zone].

Indian Monsoons

- The term monsoon has been derived from the Arabic word **mausin** or from the Malayan word **monsin** meaning **'season'.**
- Monsoons are **seasonal winds** (Rhythmic wind movements)(Periodic Winds) which **reverse** their direction with the change of season.
- The monsoon is a double system of seasonal winds – They flow from sea to land during the summer and from land to sea during winter.
- Some scholars tend to treat the monsoon winds as **land and sea breeze** on a large scale.
- Monsoons are peculiar to Indian Subcontinent, South East Asia, parts of Central Western Africa etc..
- They are more pronounced in the Indian Subcontinent compared to any other region.
- Indian Monsoons are **Convection cells** on a very large scale.
- They are **periodic or secondary winds** which **seasonal reversal in wind direction**.
- India receives south-west monsoon winds in summer and north-east monsoon winds in winter.
- South-west monsoons are formed due to intense low pressure system formed over the Tibetan plateau.
- North-east monsoons are associated with high pressure cells over **Tibetan** and **Siberian plateaus.**
- South-west monsoons bring intense rainfall to most of the regions in India and north-east monsoons bring rainfall to mainly **south-eastern coast** of India (Southern coast of Seemandhra and the coast of Tamil Nadu.).
- Countries like **India, Indonesia, Bangladesh, Myanmar** etc. receive most of the annual rainfall during south-west monsoon season where as **South East China, Japan** etc., during north-east rainfall season.

Factors responsible for south-west monsoon formation

- *Intense heating of Tibetan plateau during summer months.*
- *Permanent high pressure cell in the South Indian Ocean (east to north-east of Madagascar in summer).*

Factors that influence the onset of south-west monsoons

- *Above points +*
- *Subtropical Jet Stream (STJ).*
- *Tropical Easterly Jet (African Easterly Jet).*
- *Inter Tropical Convergence Zone.*

Factors that influence the intensity of south-west monsoons

- *Strengths of Low pressure over Tibet and high pressure over southern Indian Ocean.*
- *Somali Jet (Findlater Jet).*
- *Somali Current (Findlater Current).*
- *Indian Ocean branch of Walker Cell.*
- *Indian Ocean Dipole.*

Factors responsible for north-east monsoon formation

- *Formation and strengthening of high pressure cells over Tibetan plateau and Siberian Plateau in winter.*
- *Westward migration and subsequent weakening of high pressure cell in the Southern Indian Ocean.*
- *Migration of ITCZ to the south of India.*

All these will be discussed in detail.

Mechanism of Indian Monsoons

- The origin of monsoons is not fully understood.
- There are several theories that tried to explain the mechanism of monsoons.

Classical Theory

- Monsoons are mentioned in scriptures like the **Rig Veda**. But these scriptures didn't make any mention of the monsoon mechanism.
- The first scientific study of the monsoon winds was done by **Arab traders**.
- Arab traders used the sea route to carry out trade with India and monsoon patterns were of prime importance for them.
- In the tenth century, **Al Masudi**, an Arab explorer, gave an account of the **reversal of ocean currents and the monsoon winds** over the north Indian Ocean.
- In seventeenth century, Sir Edmund Halley explained the monsoon as resulting from **thermal contrasts** between continents and oceans due to their differential heating.

Modern Theories

- Besides differential heating, the development of monsoon is influenced by the shape of the continents, orography (mountains), and the conditions of **air circulation in the upper troposphere {jet streams}.**
- Therefore, Halley's theory has lost much of its significance and modern theories based on air masses and jet stream are becoming more relevant.

Indian Monsoons – Classical Theory: Sir Edmund Halley's Theory

Summer Monsoon

- In summer the sun's apparent path is vertically over the Tropic of Cancer resulting in high temperature and low pressure in Central Asia.
- The pressure is sufficiently high over Arabian Sea and Bay of Bengal. Hence winds flowed from Oceans flow towards landmass in summer.
- This air flow from sea to land bring heavy rainfall to the Indian subcontinent.

Winter Monsoon

- In winter the sun's apparent path is vertically over the Tropic of Capricorn.
- The north western part of India grows colder than Arabian Sea and Bay of Bengal and the flow of the monsoon is reversed.
- The basic idea behind Classical theory is similar to land and sea breeze formation except that in the case of monsoons the day and night are replaced by summer and winter.

Drawbacks: The monsoons do not develop equally everywhere on earth and the thermal concept of Halley fails to explain the intricacies of the monsoons such as the **sudden burst** of monsoons, **delay** in on set of monsoons sometimes, etc..

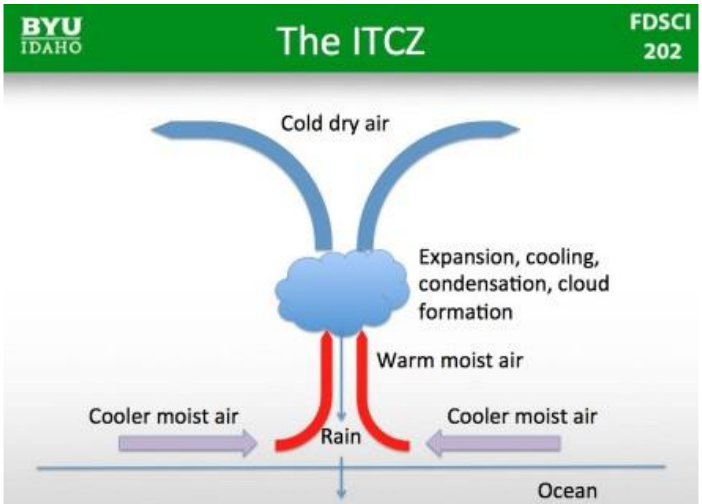
Indian Monsoons – Modern theory: Air Mass Theory

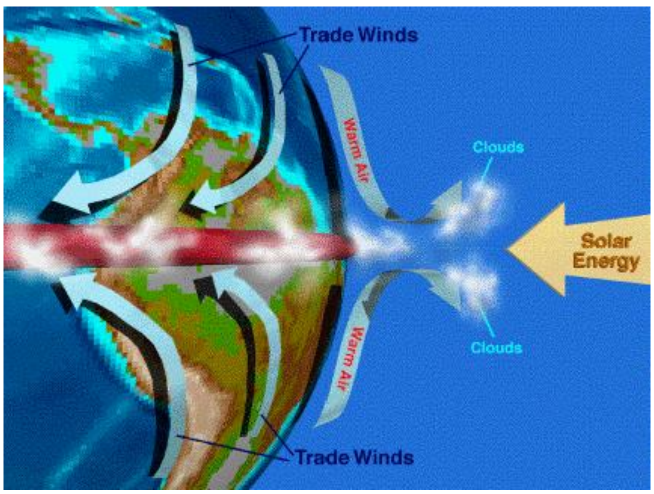
- According to this theory, the monsoon is simply a **modification of the planetary winds of the tropics.**
- The theory is based on the migration of ITCZ based on seasons.

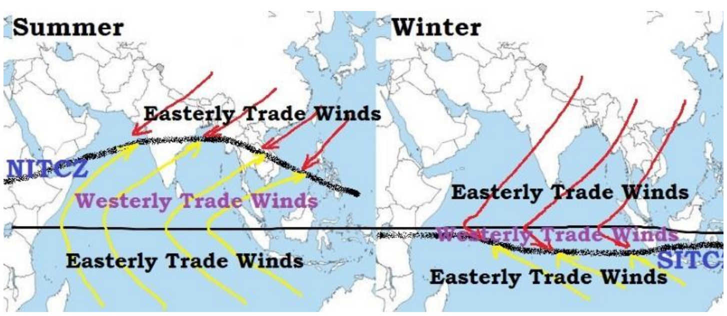
Indian Monsoons – Role of ITCZ [Inter-Tropical Convergence Zone]

- The southeast trade winds in the southern hemisphere and the northeast trade winds in the northern hemisphere meet each other near the equator.

- The meeting place of these winds is known as the **Inter-Tropical Convergence Zone (ITCZ).**







- This is the region of ascending air, **maximum clouds** and **heavy rainfall**.
- The location of ITCZ **shifts** north and south of equator with the change of season.
- In the summer season, the sun shines vertically over the Tropic of Cancer and the ITCZ shifts northwards.
- The southeast trade winds of the southern hemisphere cross the equator and start blowing in southwest to northeast direction under the influence of **Coriolis force**.
- These displaced trade winds are called south-west monsoons when they blow over the Indian sub-continent.
- The front where the south-west monsoons meet the north-east trade winds is known as the **Monsoon Front (ITCZ). Rainfall occurs along this front.**
- In the month of July the ITCZ shifts to 20°- 25° N latitude and is located in the Indo-Gangetic Plain and the south-west monsoons blow from the Arabian Sea and the Bay of Bengal. The ITCZ in this position is often called the **Monsoon Trough [maximum rainfall]**.
- The seasonal shift of the ITCZ has given the concept of Northern Inter-Tropical Convergence Zone (NITCZ) in summer (July – rainy season) and Southern Inter-Tropical Convergence Zone (SITCZ) in winter (Jan – dry season).
- NITCZ is the zone of clouds and heavy rainfall that effect India.

Indian Monsoon Mechanism – Jet Stream Theory. Role of Sub-Tropical Jet Stream (STJ). Why no south-west monsoons during winter? Why no south-west monsoons in March – May (summer)?

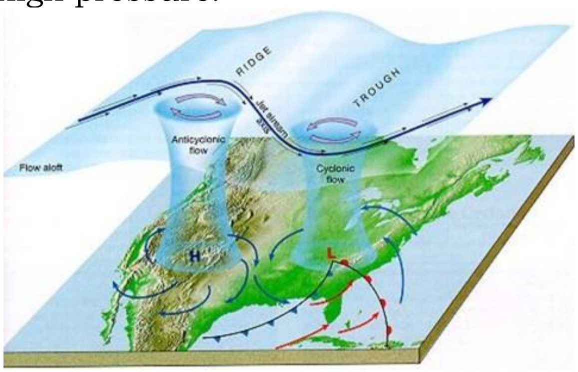
Indian Monsoon Mechanism – Jet Stream Theory

Indian Monsoon Mechanism – Modern Theory: Jet Stream Theory.

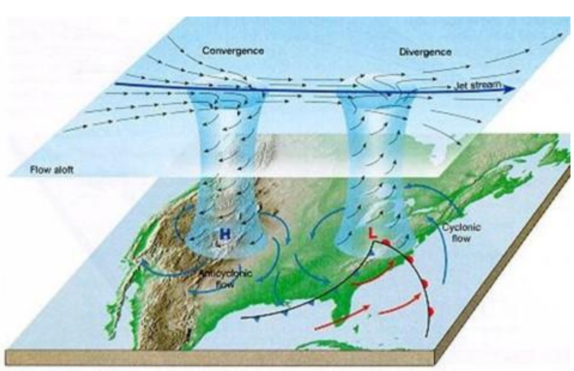
- Jet stream Theory is the latest theory regarding the origin of the monsoons and has earned worldwide acceptance from the meteorologists.
- To understand how Jet streams affect Indian monsoons, we need to know the basic mechanism of Jet Stream induced weather conditions.

How Jet Streams Affect Weather?

- Jet streams have distinct **peaks (ridges)** and **troughs.**
- Ridges occur where the warm air mass pushes against the cold air mass. Troughs occur where cold air mass drops into warm air.
- The region on earth below the trough is at low pressure and the region below ridge is at high pressure.



- This condition occurs due to weakening of jet stream due to lesser temperature contrast between sub-tropics and temperate region (Our concern is STJ only).
- Usually the trough region [the region exactly below the jet stream trough] creates cyclonic condition (low pressure) at the surface of earth whereas the ridge regions creates anticyclonic condition.
- Troughs create upper level divergence which is associated with convergence at the surface (low pressure – cyclonic conditions) and ridges create upper level convergence which is associated with divergence at the surface (high pressure – cyclonic conditions).
- These ridges and troughs give rise to jet streaks which are also responsible for cyclonic and anticyclonic weather conditions at the surface.



- The winds leaving the jet streak are rapidly **diverging**, creating a lower pressure at the upper level (Tropopause) in the atmosphere. The air below rapidly replaces the upper outflowing winds. This in turn creates the **low pressure at the surface**. This surface low pressure creates conditions where the surrounding surface winds rush inwards. The Coriolis effect creates the cyclonic rotation (cyclonic vortex) that is associated with depressions [low pressure cells].
- The winds entering the jet streak are rapidly converging because of the high pressure at the upper level (Tropopause) in the atmosphere. This convergence at upper troposphere leads to divergence (high pressure) at the surface (anticyclonic condition).
- The Coriolis effect creates the anticyclonic rotation that is associated with **clear weather.**

But how does this mechanism of jet streams influence Indian Monsoons?

Indian Monsoon Mechanism – Role of Sub-Tropical Jet Stream (STJ)

- Sub-Tropical Jet stream plays a significant role in both hindering the monsoon winds as well as in quick onset of monsoons.

STJ – Sub-Tropical Jet Stream

- Sub-Tropical Jet stream is a narrow band of fast moving air flowing from **west to east [Westerlies].**
- STJ in northern hemisphere flows between 25° to 35° N in the upper troposphere at a height of about 12-14 km (all this already discussed in previous posts on Jet Streams). (Here we will consider STJ only. Polar Jet has no influence on Indian monsoons).
- The wind speeds in a westerly jet stream are commonly 150 to 300 km p.h. with extreme values reaching 400 km p.h.

The burst of monsoons depends upon the upper air circulation which is dominated by STJ.

Seasonal Migration of Sub-Tropical Jet Stream – STJ

- *In winter STJ flows along the southern slopes of the Himalayas but in summer it shifts northwards, rather dramatically, and flows along the northern edge of Himalayas in early June and in late summer (July-August) along the northern edge of the Tibetan Plateau.*
- *The periodic movement of the Jet stream is often the indicator of the onset (STJ shits to the north of Himalayas in a matter of days) and subsequent withdrawal (STJ returns back to its position – south of Himalayas) of the monsoon.*
- *Northward movement of the subtropical jet is the first indication of the onset of the monsoon over India.*

Sub-Tropical Jet Stream – STJ in Winter

- Westerly jet stream blows at a very high speed during winter over the sub-tropical zone.
- This jet stream is bifurcated by the Himalayan ranges and Tibetan Plateau.
- The two branches reunite off the east coast of China.
- The northern branch of this jet stream blows along the northern edge of the Tibetan Plateau.
- The southern branch blows to the south of the Himalayan ranges along 25° north latitude.
- A strong latitudinal thermal gradient (differences in temperature), along with other factors, is responsible for the development of southerly jet.

Western Disturbances

Meteorologists believe that southern branch of jet stream exercises a significant influence on the winter weather conditions in India.

The upper jet is responsible for steering of the **western depressions [Western Disturbances]** from the Mediterranean Sea.

Some of the depressions continue eastwards, redeveloping in the zone of jet stream confluence about 30° N, 105° E (near east coast of China).

Winter rain and heat storms in north-western plains and occasional heavy snowfall in hilly regions are caused by these disturbances.

These are generally followed by cold waves in the whole of northern plains.

- The southern branch is stronger, with an average speed of about 240 km compared with 70 to 90 km p.h. of the northern branch.
- Air subsiding beneath this upper westerly current gives dry out blowing northerly winds from the subtropical anticyclone over northwestern India and Pakistan.

Why no south-west monsoons during winter?

- **Reason 1:** ITCZ has left India (the winds that blow over India are mostly offshore — land to land or land to ocean — so they carry no moisture).
- **Reason 2:** During winter, the southern branch of STJ is strong and is to the south of Himalayas. The ridge of the jet lies over north-western India and is associated with strong divergence of winds and creates a high pressure region (sub-tropical high pressure belt) over entire north India. *[This is how the mechanism of jet streams influence Indian Monsoons in winter season]*
- **Reason 3:** There is already a strong high pressure over Tibet. [High Pressure due to STJ + High Pressure over Tibet = strong divergence = no rainfall]

Sub-Tropical Jet Stream – STJ in Summer

- With the beginning of summer in the month of March, the STJ [upper westerlies] start their northward march.
- The southerly branch of STJ remains positioned south of Tibet, although weakening in intensity.

- The weather over northern India becomes hot, dry and squally due to larger incoming solar radiation and hot winds like **loo.**
- Over India, the **Equatorial Trough (ITCZ)** pushes northwards with the weakening of the STJ [upper westerlies] south of Tibet, but the burst of the monsoon does not take place until the upper-air circulation has switched to its summer pattern.
- By the end of May the southern jet breaks and later it is diverted to the north of Tibet Plateau and there is sudden burst of monsoons (the ridge moves northwards into Central Asia = high pressure over north-west India moves northwards into Central Asia = makes way for south-west monsoon winds). An Easterly jet emerges over peninsular India with the northward migration of STJ.
- The upper air circulations are reversed with the emergence of Easterly jet [convergence in upper layers is replaced by divergence == divergence in lower layers is replaced with convergence == high pressure at lower layers is replaced by low pressure system]. The easterly winds become very active in the upper troposphere and they are associated with westerly winds in the lower troposphere (south-west monsoon winds).
- Western and eastern jets flow to the north and south of the Himalayas respectively. The eastern jet becomes powerful and is stationed at 15° N latitude.
- This results in more active south-west monsoon and heavy rainfall is caused.

Why no south-west monsoons in March – May (summer)?

- There is good sun's insolation from March – May but still there is no s-w monsoons.

Reason: The ridge region of Southern branch of STJ creates strong divergence (high pressure) in north-west India. The diverging air blocks incoming winds and prevents strong convergence of winds along ITCZ.

- During the summer season in the Northern Hemisphere, low pressure areas develop at the ground surface near Peshawar (Pakistan) and north-west India due to intense heating of ground surface during April, May, and June.
- As long as the position of the upper air jet stream is maintained above the surface low pressure (to the south of Himalayas), the dynamic anti-cyclonic conditions persist over north-west India.
- The winds descending from the upper air high pressure [because of the trough of STJ] obstructs the ascent of winds from the surface low pressure areas, with the result that the weather remains warm and dry.
- This is why the months of April and May are generally dry and rainless in spite of high temperatures (low pressure on land) and high evaporation.

Indian Monsoons – Role of Tropical Easterly Jet (TEJ) [African Easterly Jet], Indian Monsoons – Role of Tibet, Indian Monsoons – Role of Somali Jet and Indian Monsoons – Role of Indian Ocean Dipole.

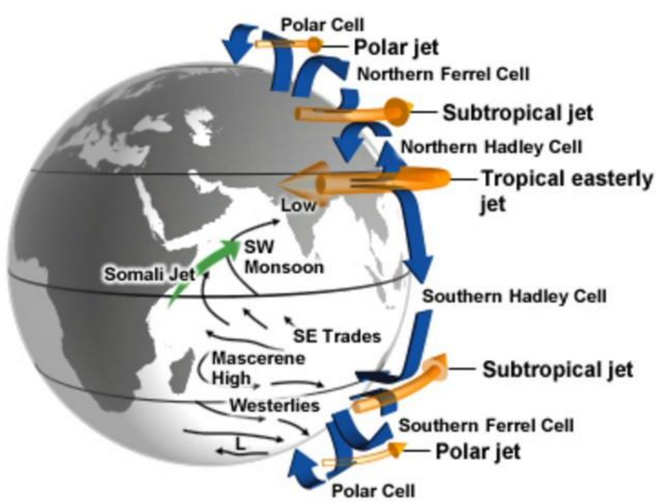
Indian Monsoons – Role of Tropical Easterly Jet (TEJ) [African Easterly Jet]

- The establishment and maintenance of the TEJ is not fully understood but it is believed that the jet may be caused by the uniquely **high temperatures and heights** over the Tibetan Plateau during summer.
- The TEJ plays an important role in **kick starting southwest monsoon**.
- This jet descends over the Indian Ocean (near Madagascar) and intensifies its high pressure cell so as to move as south-west monsoon.

Tropical Easterly Jet (TEJ)

- There are major high velocity winds in the lower troposphere called **low-level jets (LLJs).**

- In the tropics, the most prominent of these are the **Somali Jet** and the **African Easterly Jet [Tropical Easterly Jet].**
- The TEJ is a unique and dominant feature of the northern hemispheric summer over southern Asia and northern Africa. The TEJ is found near between 5° and 20°N.
- It is fairly persistent in its direction, and intensity from June through the beginning of October. It's position fluctuates between 5° and 20°N.
- *TEJ comes into existence quickly after the STJ has shifted to the north of the Himalayas (Early June).*
- TEJ flows from east to west over peninsular India at 6 – 9 km and over the Northern African region.
- The formation of TEJ results in the **reversal of upper air circulation patterns [High pressure switches to low pressure]** and leads to the quick onset of monsoons.
- Recent observations have revealed that the intensity and duration of heating of Tibetan Plateau has a direct bearing on the amount of rainfall in India by the monsoons.

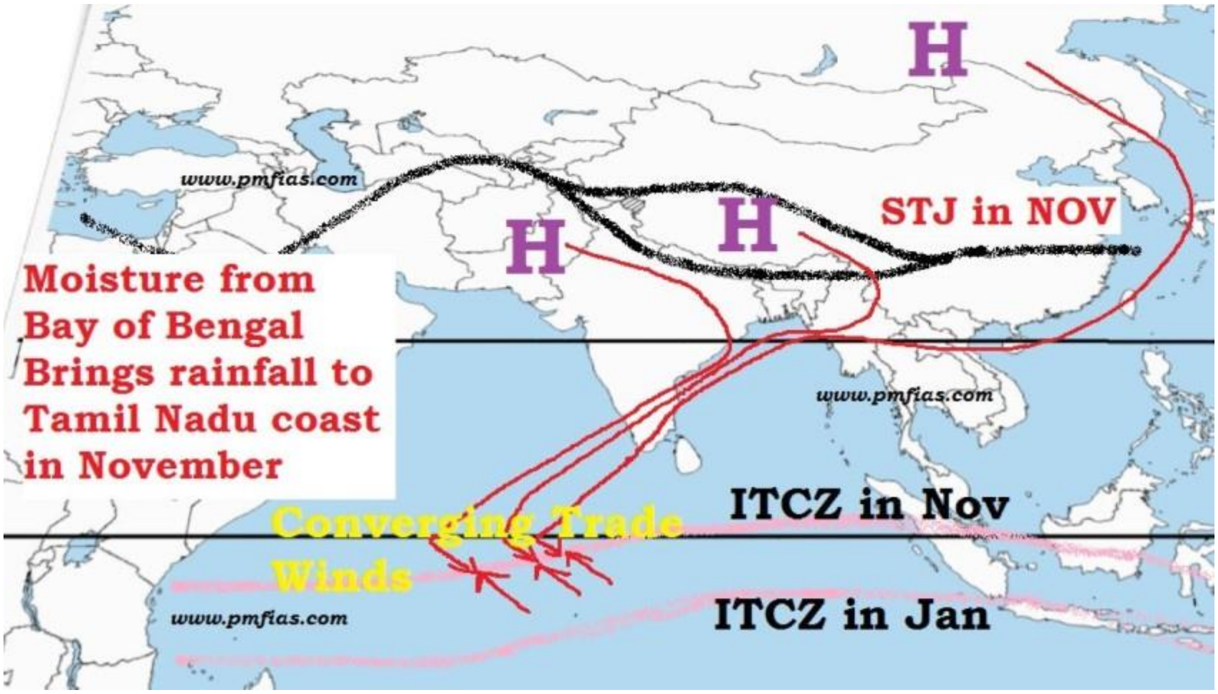


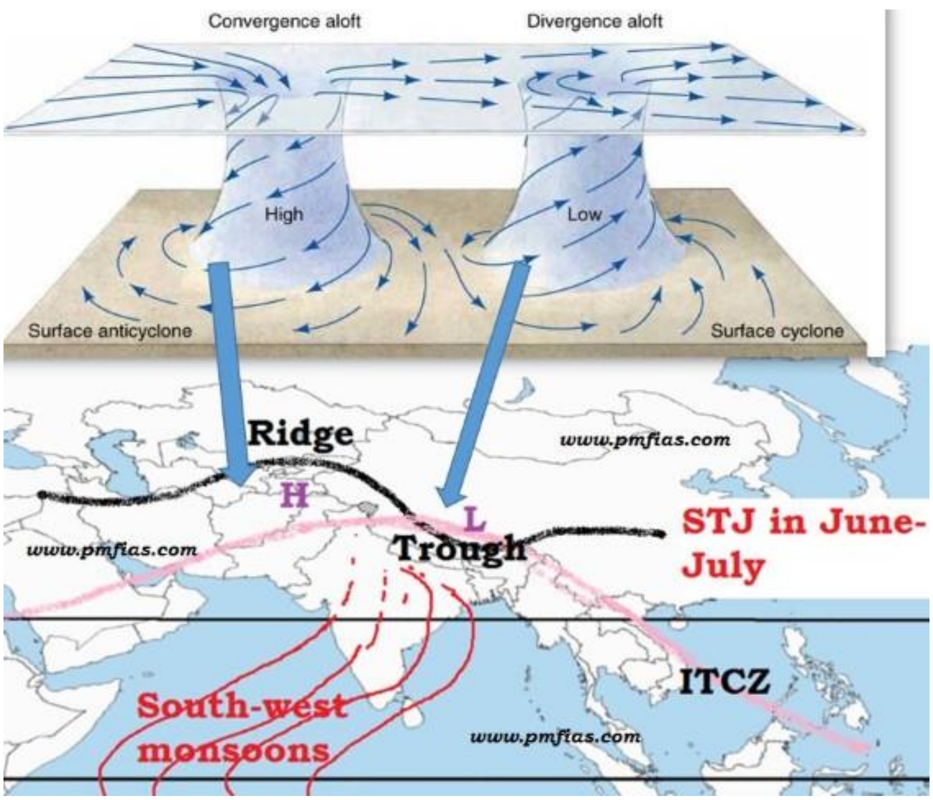
- When the summer temperature of air over Tibet remains high for a sufficiently long time, it helps in strengthening the easterly jet and results in heavy rainfall in India.
- **The easterly jet does not come into existence if the snow over the Tibet Plateau does not melt. This hampers the occurrence of rainfall in India.**
- **Therefore, any year of thick and widespread snow over Tibet will be followed by a year of weak monsoon and less rainfall.**

Indian Monsoons – Role of Tibet

- The Tibetan Plateau is an enormous block of highland acting as a formidable barrier.
- Due to its protruded height it receives 2-3°C more insolation than the neighboring areas.
- The plateau affects the atmosphere in two ways: **(a) as a mechanical barrier, and (b) as a high- level heat sources.**
- At the beginning of June the subtropical jet stream is completely withdrawn from India and occupies a position along 40° N (to the north of Tibetan Plateau).
- The plateau **accentuates** the northward displacement of the jet stream. Hence the burst of monsoon in June is prompted by the Himalayas and not by the thermally induced low pressure cell over Tibet. **(Tibetan plateau is responsible for south-west monsoons. But it is the STJ that facilitates sudden outburst of monsoons with its sudden northward migration)**
- In the middle of October the plateau proves to be the most important factor in causing the advance of the jet south of the Himalayas or bifurcating it into two parts.
- The winter Tibetan Plateau cools rapidly and produces a high pressure cell. (Cyclonic condition over Tibet ceases and an anticyclonic condition is established). The high pressure cell over Tibet strengthens N-E monsoons.
- Tibet gets heated in summer and is 2°C to 3°C warmer than the air over the adjoining regions.
- Because the Tibet Plateau is a source of heat for the atmosphere, it generates an area of rising air (convergence)(intense low pressure cell).
- During its ascent the air spreads outwards in upper troposphere (divergence) and gradually sinks (subsidence) over the equatorial part of the Indian Ocean.

- It finally approaches the west coast of India as a return current from a south-westerly direction and is termed as equatorial westerlies.
- It picks up moisture from the Indian Ocean and causes rainfall in India and adjoining countries.

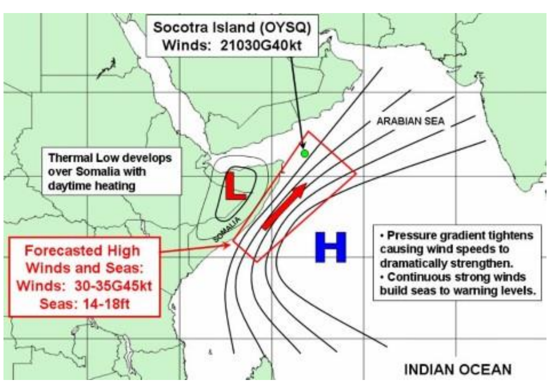




Indian Monsoons – Role of Somali Jet

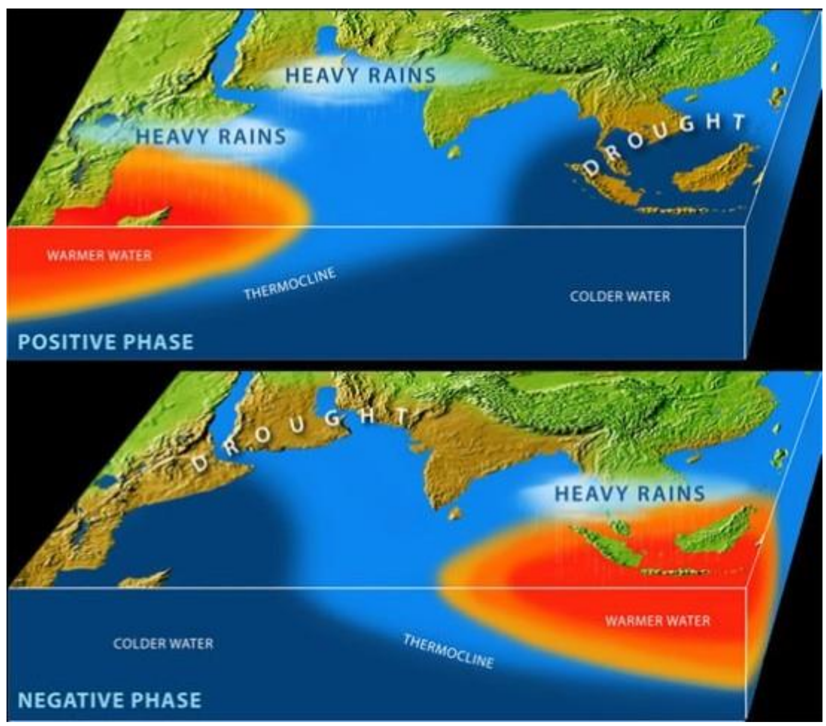
- Polar and subtropical jet streams are the permanent jet streams which greatly influence the weather of temperate regions.
- Temporary jet streams are narrow winds with speeds more than 94 kph in the upper, middle and sometimes in lower troposphere. They are few. Important ones are Somali Jet and The African Easterly jet or Tropical Easterly Jet.

- These two jet streams play an important role in the formation and progression of Indian Monsoons.
- The progress of the southwest monsoon towards India is greatly aided by the onset of Somali jet that transits Kenya, Somalia and Sahel.
- It was observed to flow from Mauritius and the northern part of the island of Madagascar before reaching the coast of Kenya at about 3° S.
- **It strengthens permanent high near Madagascar and also helps to drive S-W monsoons towards India at a greater pace and intensity.**
- The importance of the low level jet arises from the fact that its path around 9° N coincides with a zone of coastal upwelling.
- As the strong winds drive away the surface coastal waters towards the east, extremely cold water from the depths of the sea rise upwards to preserve the continuity of mass.
- The peculiar feature of Somali Current is **reversal in direction** with the onset of the summer monsoon.
- In winter, this current is from north to the south running southwards from the coast of Arabia to the east African coastline; but with the advent of the summer monsoon it reverses its direction and flows from the south to the north.



Indian Monsoons – Role of Indian Ocean Dipole

- Indian ocean Dipole is a recently discovered phenomena that has a significant influence on Indian monsoons.
- Indian ocean Dipole is a SST anomaly (Sea Surface Temperature Anomaly – different from normal) that occurs occasionally in Northern or Equatorial Indian Ocean Region (IOR).
- The Indian Ocean Dipole (IOD) is defined by the difference in sea surface temperature between two areas (or poles, hence a dipole) – a western pole in the Arabian Sea (western Indian Ocean) and an eastern pole in the eastern Indian Ocean south of Indonesia.
- IOD develops in the equatorial region of



Indian Ocean from April to May peaking in October.
- With a positive IOD winds over the Indian Ocean blow from east to west (from Bay of Bengal towards Arabian Sea). This results in the Arabian Sea (western Indian Ocean near African Coast) being much warmer and eastern Indian Ocean around Indonesia becoming colder and dry.
- In the negative dipole year, reverse happens making Indonesia much warmer and rainier.

- Positive IOD is good for Indian Monsoons as more evaporation occurs in warm water.
- Similar to ENSO, the atmospheric component of the IOD is named as Equatorial Indian Ocean Oscillation (EQUINOO)(Oscillation of pressure cells between Bay of Bengal and Arabian Sea).
- During the positive phase of the 'Equatorial Indian Ocean Oscillation (EQUINOO),' there is enhanced cloud formation and rainfall in western part of the equatorial ocean near the African coast while such activity is suppressed near Sumatra.
- While EQUINOO and IOD go in step during strong positive IOD events, they do not always do so.
- Indian Monsoons |ITCZ|Inter-Tropical Convergence Zone
- Indian Monsoons Mechanism|Jet Stream Theory
- Indian Monsoons – Easterly Jet|Tibet|Somali Jet
- Indian Monsoons – South West|North East Monsoons <-- You are Here

How Jet Streams affect the Monsoons in the Indian Sub-Continent?

Summing up all the points above.

- As the summer time approaches, there is increased solar heating of the Indian subcontinent and the Tibetan Plateau.
- In the peak summer months (25th of May – 10th of Jun), with the apparent northward movement of the sun, the southern branch of the SJT, which flows to the south of the Himalayas, shifts to the north of the Himalayas.
- When the sun's position is about to reach the Tropic of Cancer (June), the SJT shifts to the north of the Tibetan Plateau (1st of Jun – 20th of June). The ITCZ is close to its peak position over the Tibetan Plateau.
- The altitude of the mountains initially disrupts the jet but once it has cleared the summits it is able to reform over central Asia.
- Its movement towards the north is one of the main features associated with the onset of the monsoon over India.
- With the northward shift of SJT, an Easterly Jet is formed over the Indian plains. It generally forms in the first week of June and lasts till late October.
- It can be traced in the upper troposphere right up to the west coast of Africa.
- The northward shift of SJT and ICTZ moves the subtropical high pressure belt to the north of the Tibetan Plateau and the Easterly Jet creates a low pressure region in the Indian plains (Easterly Jet creates anticyclonic conditions in upper troposphere).
- This low pressure in the northern plains coupled with the intense low of the Tibetan Plateau leads to the sudden onset of south-west monsoons (1st of Jun – 20th of June).
- The monsoon cell is situated between the Indian Ocean (North of Madagascar)(High Pressure Cell) and Tibetan plateau (Low Pressure Cell).
- In summer the sub-tropical easterly jet fluctuates between the plains region of India and peninsular India varying the intensity of rainfall from location to location.
- During March to May, the building up of this cell is blocked by the STJ which tends to blow to the south of the Himalayas (Northwest India and Plains region are occupied by Subtropical High Pressure Belt. This high pressure belt undermines the influence of low pressure cell over Tibet).
- As long as the STJ is in this position the development of summer monsoons is inhibited (the high pressure belt stays over north India).
- With the STJ out of the way (high pressure belt migrates to the north of Tibet) the sub continental monsoon cell develops (Somali Jet) very quickly indeed, often in a matter of a few days.
- Warmth and moisture are fed into the cell by a lower level tropical jet stream which

brings with it air masses laden with moisture from the Indian Ocean.

- The end of the monsoon season is brought about when the atmosphere over the Tibetan Plateau begins to cool (August – October), this enables the STJ to transition back across the Himalayas.
- With the southward shift of ITCZ, subtropical high pressure belt returns back to the Indian plains and the rainfall ceases.
- This leads to the formation of a anticyclonic winter monsoon cell typified by sinking air masses over India and relatively moisture free winds that blow seaward.
- This gives rise to relatively settled and dry weather over India during the winter months.

Projects to understand monsoons

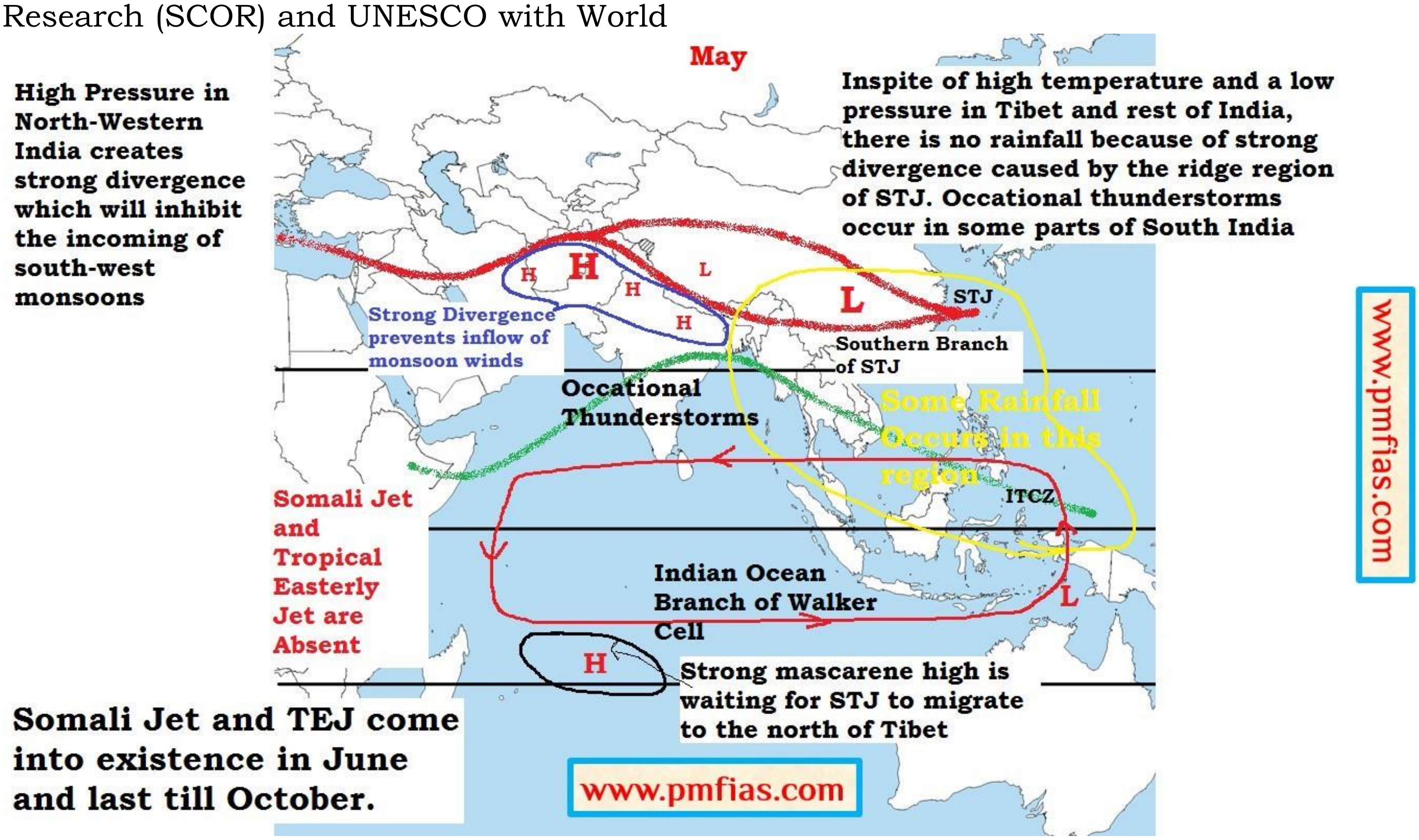
- First attempt was made during International India Ocean Expedition (HOE) from 1962 to 1965.
- It was organized jointly by the International Council of Scientific Unions (ICSU), Scientific Committee on Ocean Research (SCOR) and UNESCO with World Meteorological Organization (WMO) joining the meteorology programme.

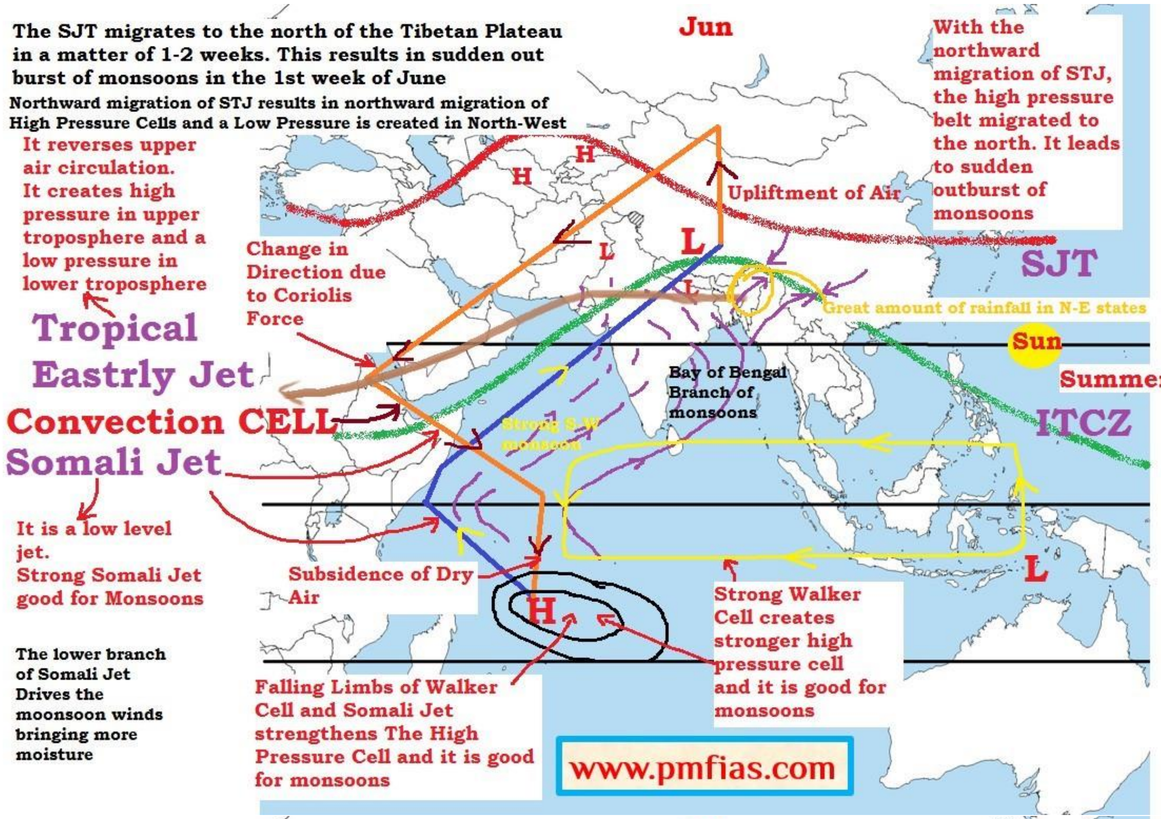
ISMEX

- Two more experiments were conducted, jointly, by India and the former USSR in 1973 and 1977, with limited participation from other countries.
- These experiments are known as the Indo-Soviet Monsoon Experiment (ISMEX) and Monsoon-77 respectively.

MONEX

- Data collection effort was made under the aegis of MONEX-1979.
- It was organised jointly by many researching organizations and the World Meteorological Organisation (WMO) under their World Weather Watch (WWW) programme.
- It is so far the largest scientific effort made to understand monsoons.
- Details are not necessary. Remember the names. They can be asked in prelims. MONEX was asked in previous papers.





Jun
The SJT migrates to the north of the Tibetan Plateau in a matter of 1-2 weeks. This results in sudden out burst of monsoons in the 1st week of June
Northward migration of STJ results in northward migration of High Pressure Cells and a Low Pressure is created in North-West
It reverses upper air circulation. It creates high pressure in upper troposphere and a low pressure in lower troposphere
Tropical Eastrly Jet
Convection CELL
Somali Jet
It is a low level jet. Strong Somali Jet good for Monsoons
The lower branch of Somali Jet Drives the moonsoon winds bringing more moisture
Change in Direction due to Coriolis Force
H
H
L
L
L
Upliftment of Air
With the northward migration of STJ, the high pressure belt migrated to the north. It leads to sudden outburst of monsoons
SJT
Great amount of rainfall in N-E states
Sun
Summer Solstice
ITCZ
Bay of Bengal Branch of monsoons
Strong S-W monsoon
Subsidence of Dry Air
H
Strong Walker Cell creates stronger high pressure cell and it is good for monsoons
Falling Limbs of Walker Cell and Somali Jet strengthens The High Pressure Cell and it is good for monsoons
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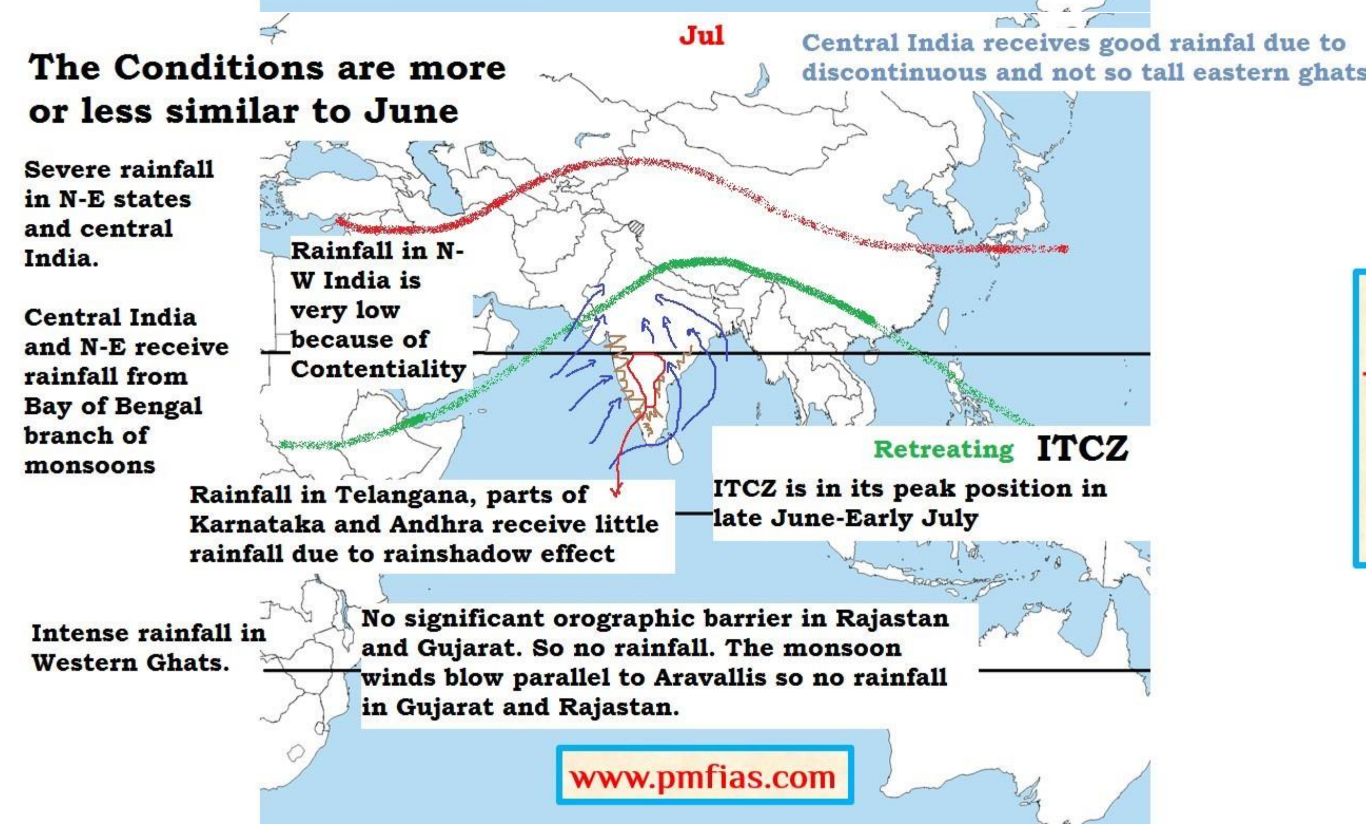

Jul
The Conditions are more or less similar to June
Central India receives good rainfal due to discontinuous and not so tall eastern ghats
Severe rainfall in N-E states and central India.
Central India and N-E receive rainfall from Bay of Bengal branch of monsoons
Rainfall in N-W India is very low because of Contentiality
Retreating ITCZ
ITCZ is in its peak position in late June-Early July
Rainfall in Telangana, parts of Karnataka and Andhra receive little rainfall due to rainshadow effect
Intense rainfall in Western Ghats.
No significant orographic barrier in Rajastan and Gujarat. So no rainfall. The monsoon winds blow parallel to Aravallis so no rainfall in Gujarat and Rajastan.
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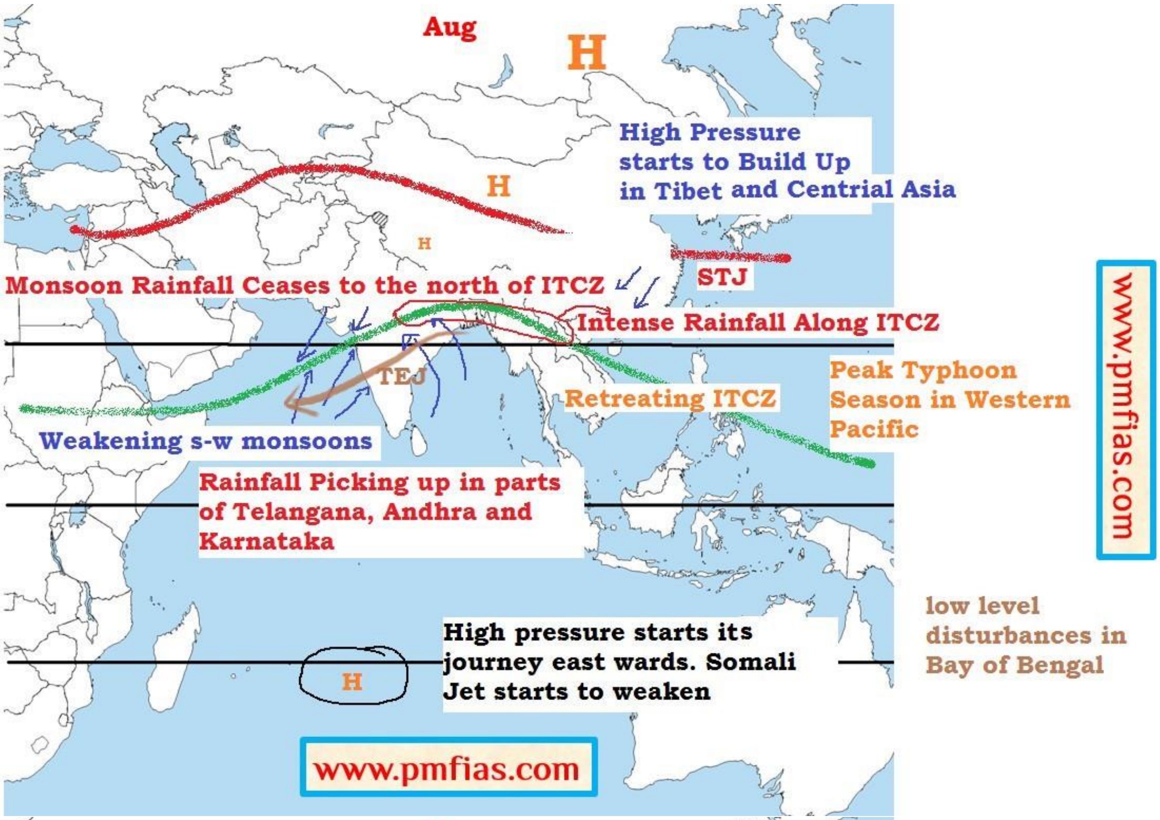

Aug
H
High Pressure starts to Build Up in Tibet and Centrial Asia
H
H
STJ
Monsoon Rainfall Ceases to the north of ITCZ
Intense Rainfall Along ITCZ
TEJ
Peak Typhoon Season in Western Pacific
Retreating ITCZ
Weakening s-w monsoons
Rainfall Picking up in parts of Telangana, Andhra and Karnataka
low level disturbances in Bay of Bengal
High pressure starts its journey east wards. Somali Jet starts to weaken
H
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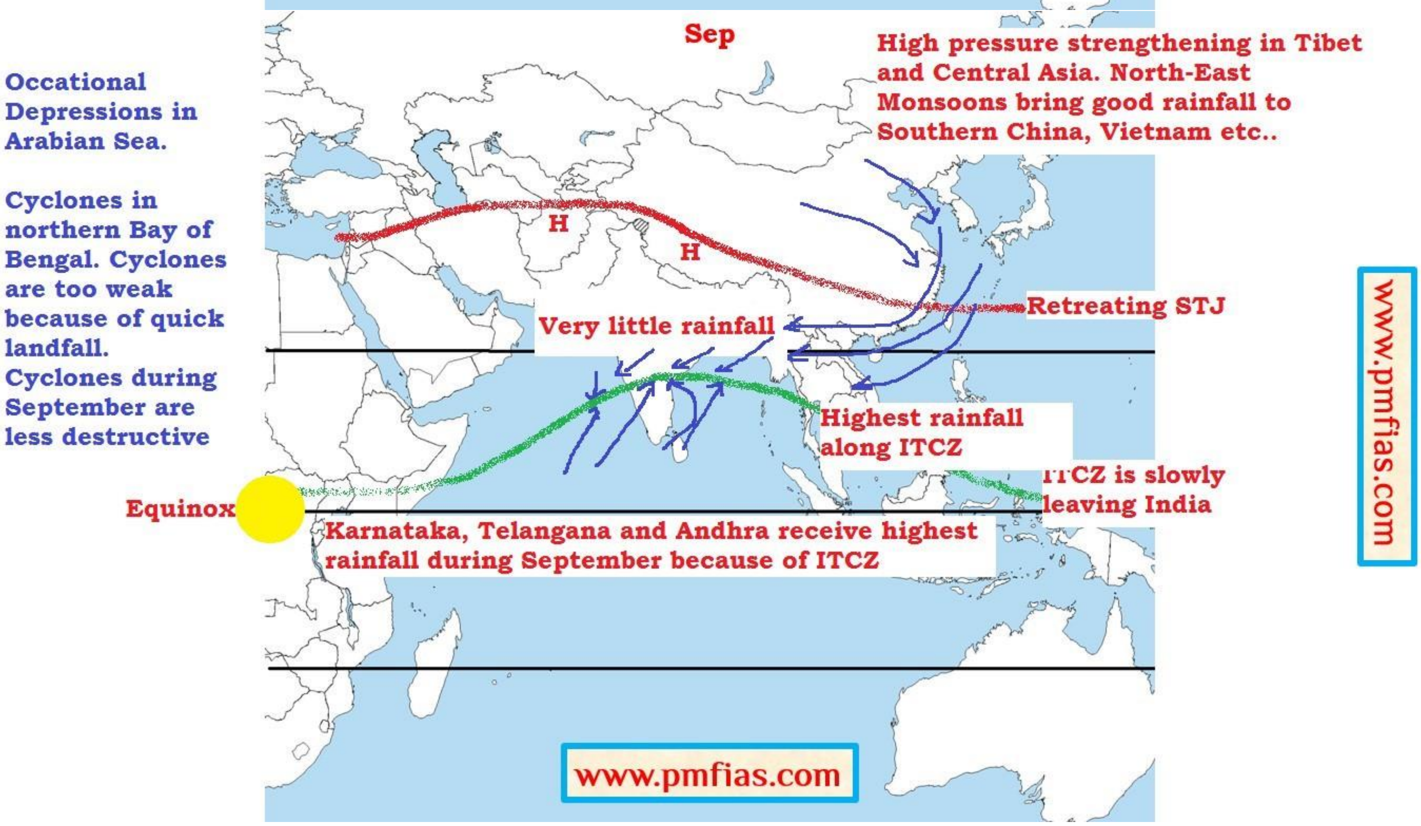

Sep
High pressure strengthening in Tibet and Central Asia. North-East Monsoons bring good rainfall to Southern China, Vietnam etc..
Occational Depressions in Arabian Sea.
Cyclones in northern Bay of Bengal. Cyclones are too weak because of quick landfall. Cyclones during September are less destructive
H
H
Retreating STJ
Very little rainfall
Highest rainfall along ITCZ
ITCZ is slowly leaving India
Equinox
Karnataka, Telangana and Andhra receive highest rainfall during September because of ITCZ
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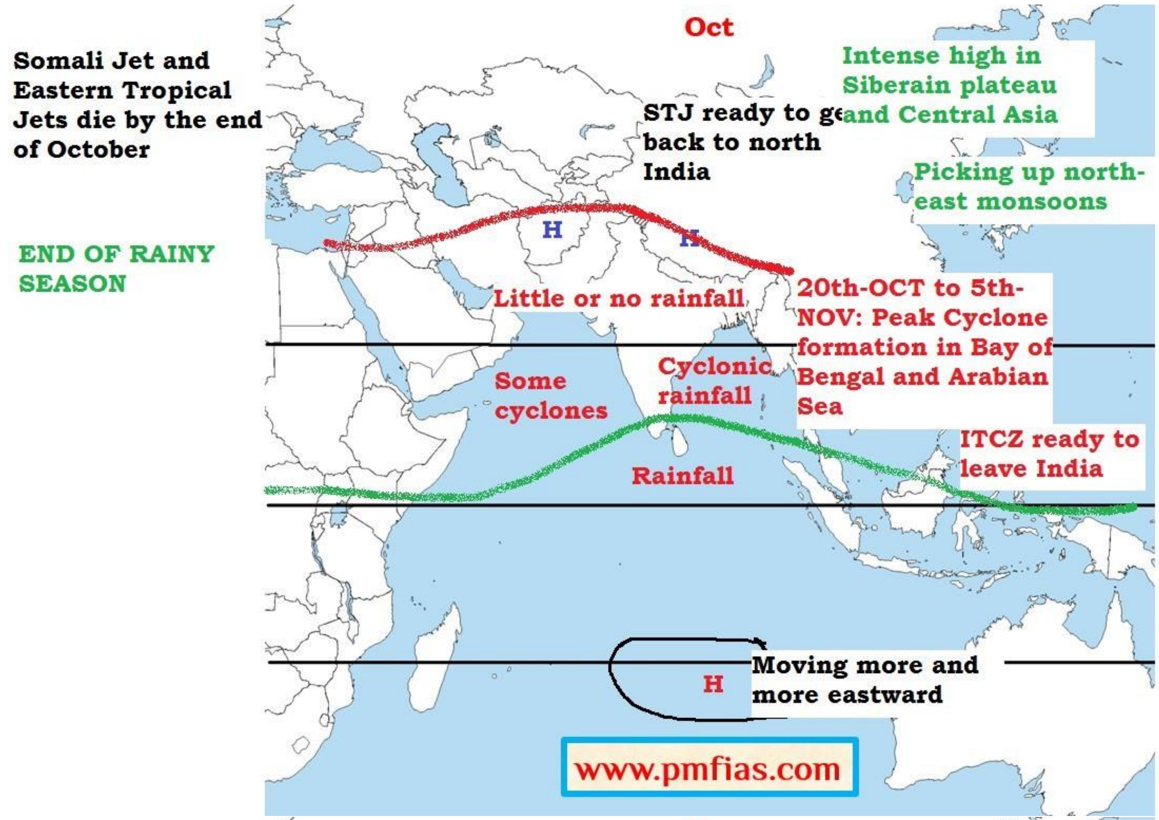
Oct
Somali Jet and Eastern Tropical Jets die by the end of October
END OF RAINY SEASON
STJ ready to go back to north India
Intense high in Siberain plateau and Central Asia
Picking up north-east monsoons
H
H
Little or no rainfall
20th-OCT to 5th-NOV: Peak Cyclone formation in Bay of Bengal and Arabian Sea
Some cyclones
Cyclonic rainfall
ITCZ ready to leave India
Rainfall
H
Moving more and more eastward
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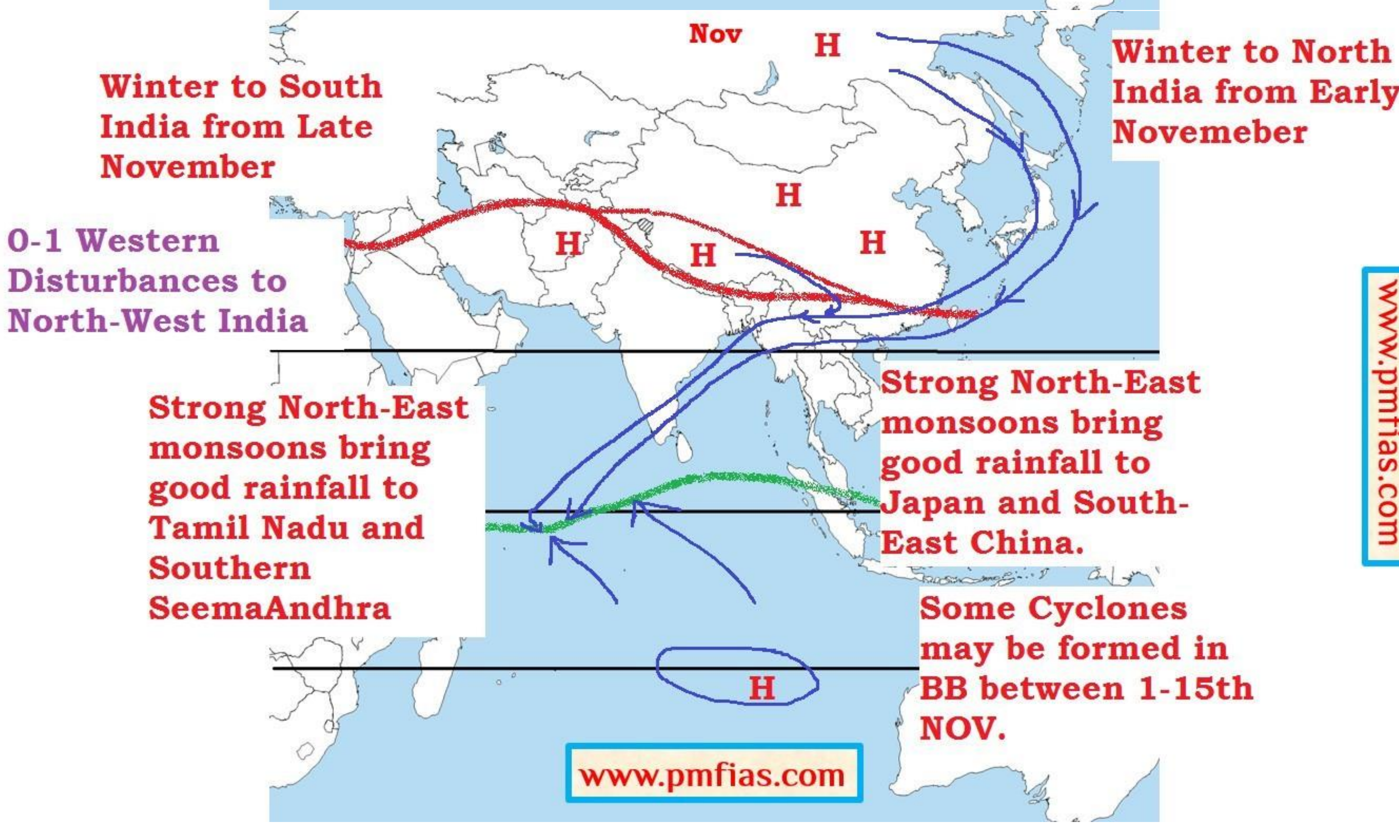
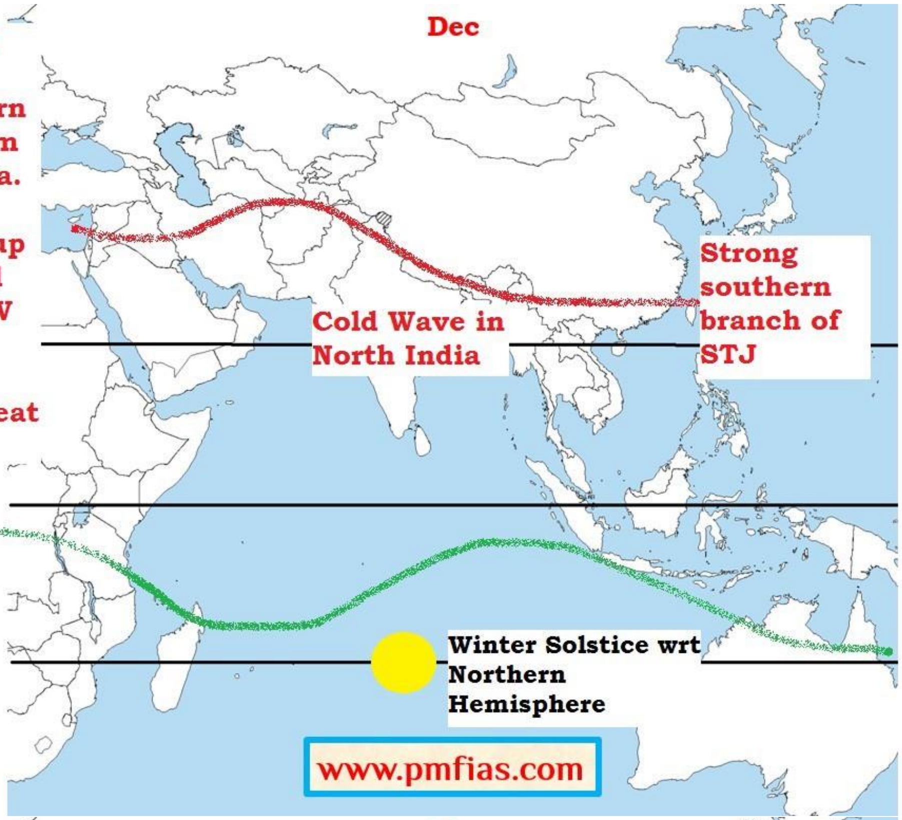
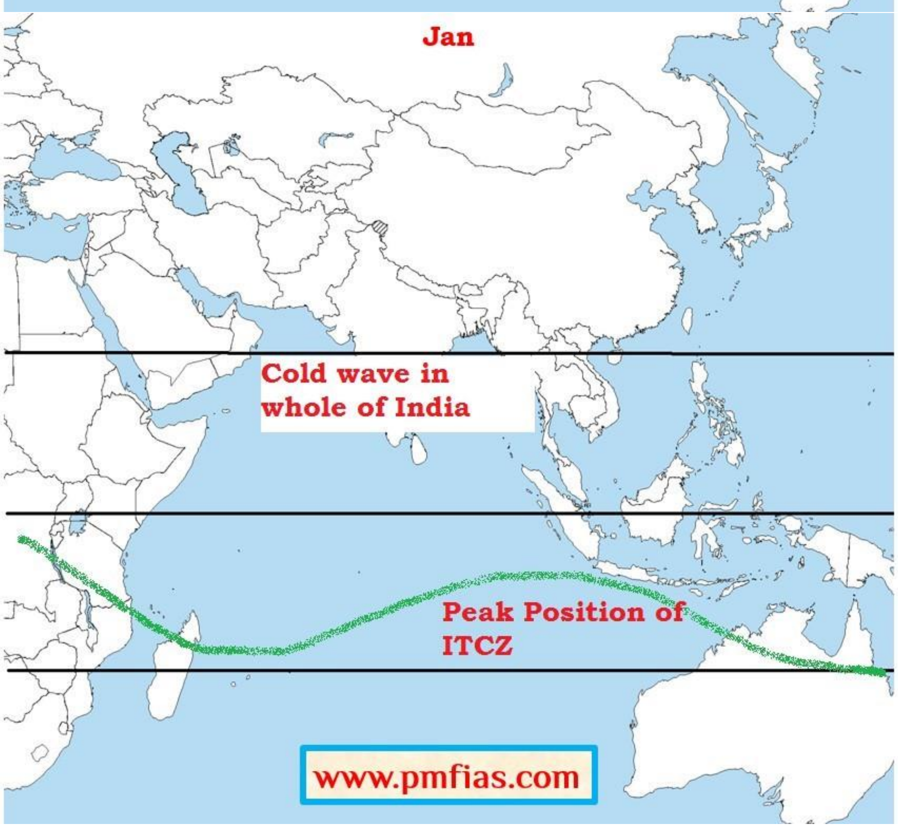

Nov
H
Winter to South India from Late November
Winter to North India from Early Novemeber
H
H
H
H
0-1 Western Disturbances to North-West India
Strong North-East monsoons bring good rainfall to Tamil Nadu and Southern SeemaAndhra
Strong North-East monsoons bring good rainfall to Japan and South-East China.
Some Cyclones may be formed in BB between 1-15th NOV.
H
www.pmfias.com

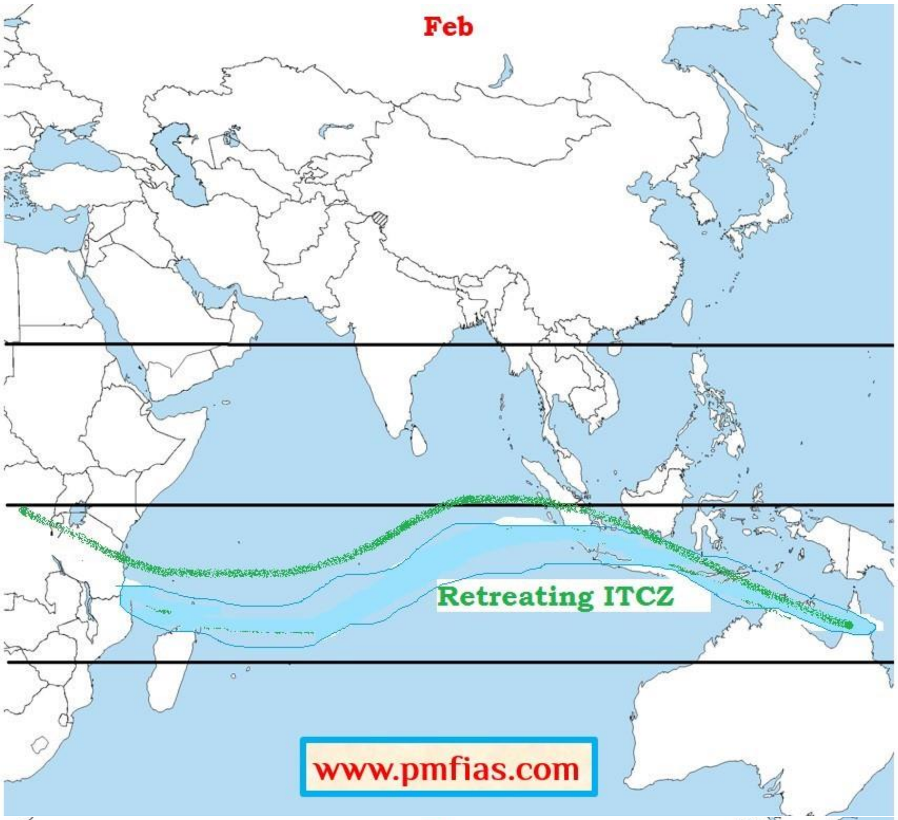
1-2 remanants of frontal storms brought by Western Disturbances (from Mediterranean Sea. On the way moisture picked up from Caspean and Black seaa) to N-W India.
They are very important for Wheat crop there

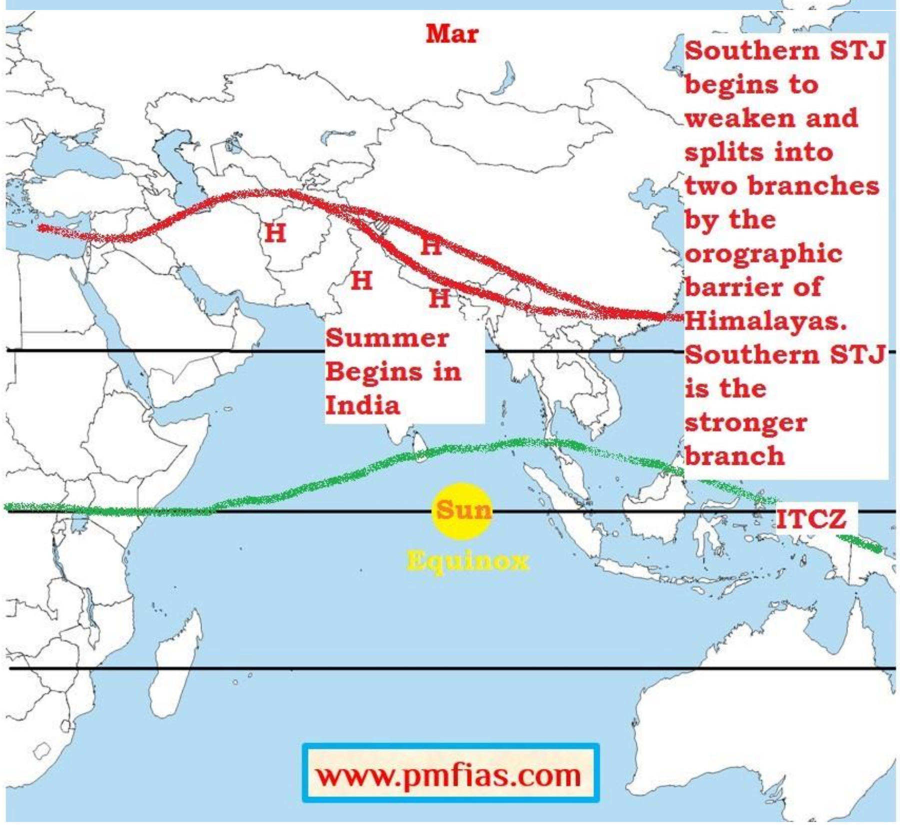


SIMILAR TO DECEMBER



Similar to DEC and JAN





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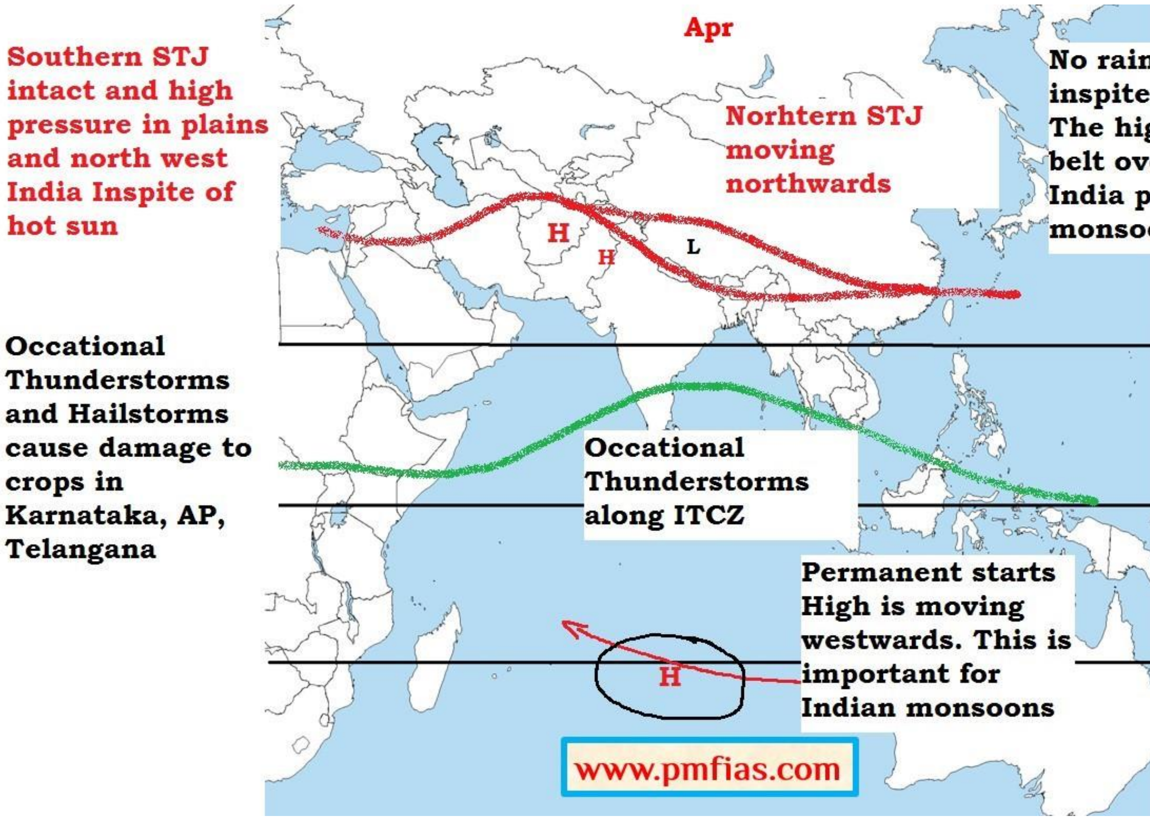
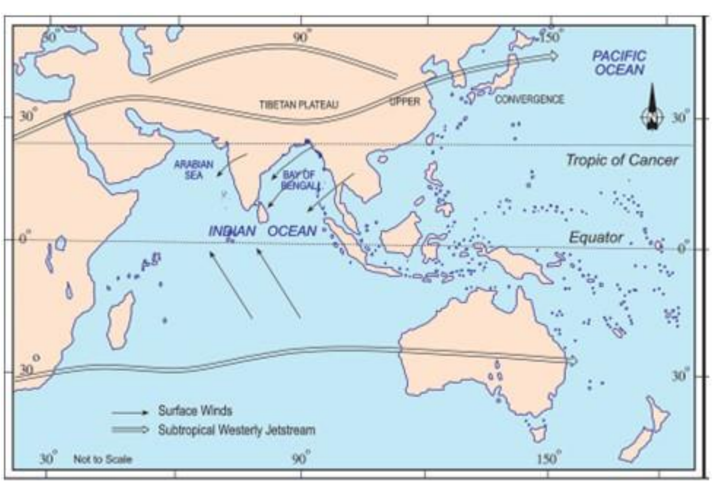


Western Disturbances - Weather associated and Importance of Western Disturbances. Cloudburst in Jammu and Kashmir, Himachal Pradesh, Uttarakhand.

Western Disturbances

- In the winter season, the sub-tropical jet (STJ) is bifurcated into two branches due to physical obstruction of the Himalayas and Tibetan Plateau.
- One branch is flows to the south of the Himalayas, while the second branch is positioned to the north of the Tibetan Plateau.

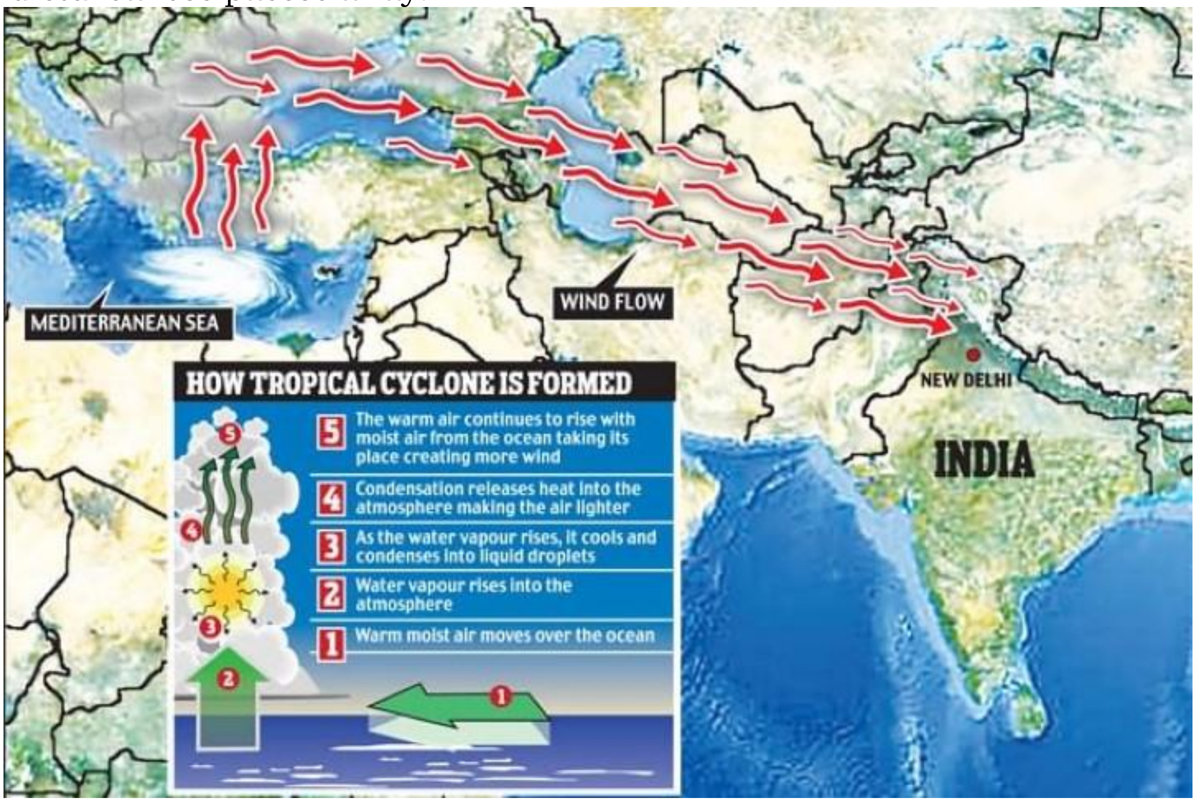


- The ridge of the jet stream creates anticyclonic (with clockwise air circulation) conditions over North-West India.
- Consequently, the winds tend to descend over the north-western parts of India, resulting into the development of atmospheric stability and dry conditions (anticyclonic condition = no rainfall).
- But the sub-tropical jet (STJ) causes periodic changes in general weather conditions.
- The STJ drives the temperate low pressures over Mediterranean Sea towards east across Afghanistan, Pakistan and reach north-west India.
- These storms are **residual frontal cyclones** which move at the height of 2000 metres from the mean sea level.
- On an average, 4 to 6 cyclonic waves reach north-western India between October and April each year.

Weather associated with Western Disturbances

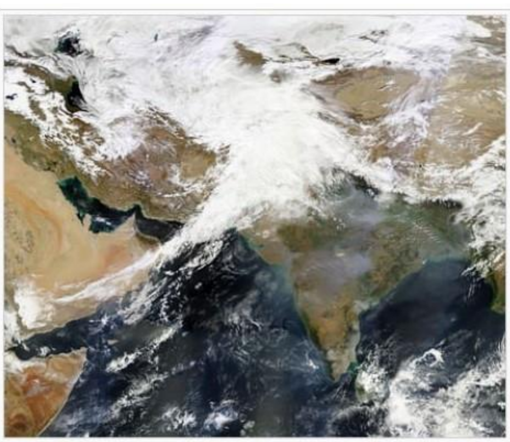
- The arrival of these temperate storms [remnants of temperate cyclones] [western disturbances] causes **precipitation** leading to an **abrupt decrease in air temperature** over North-West India.

- The weather becomes clear after the western disturbances passes away.
- Western Disturbances also bring **heavy snowfall** in the Himalayan Region and a **cold wave to north Indian plains**.



Importance of Western Disturbances

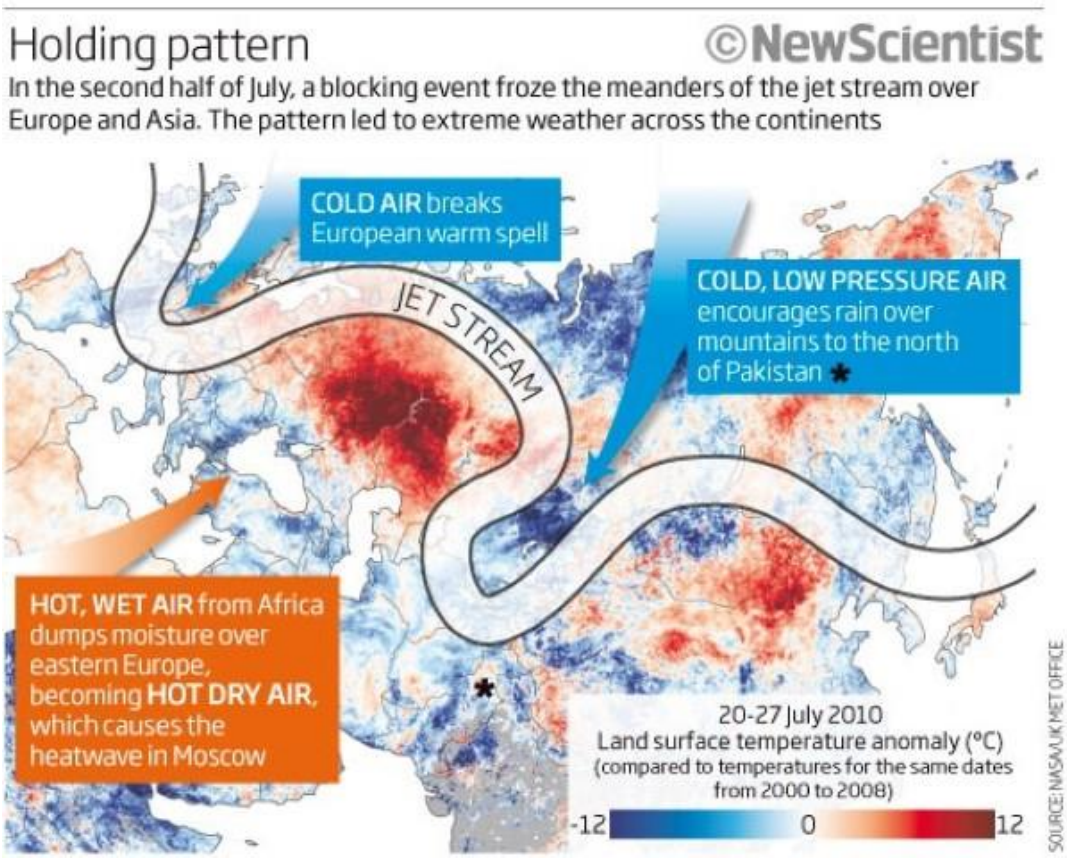
- The western disturbances affect weather conditions during the winter season up to Patna (Bihar) and give occasional rainfall which is **highly beneficial for the standing rabi crops, (wheat, barley, mustard, gram, lentil, etc.).**



Original – A strong Western Disturbance affecting northern India, Pakistan and Afghanistan. Strong Western Disturbances in winter like the one pictured bring moderate to heavy rain in low-lying areas and heavy snow to mountainous areas of the Indian Subcontinent.

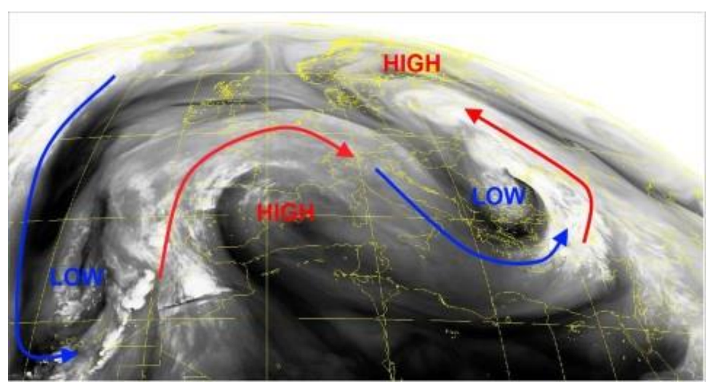
Cloudburst in Jammu and Kashmir, Himachal Pradesh, Uttarakhand

- A cloudburst is an **intense torrential rainfall** brought by a thunderstorm that lasts for a relatively short duration (few minutes to few hours).
- Cloudburst leads to **flash floods** and causes lot of damage to life and property.
- Every intense rainfall is not a Cloudburst. Cloudburst specifically occurs when an air mass with **high humidity is struck at a place due to various reasons.**



- In 2010, South-Western strip of Russia (Caucasus Region, Moscow etc.) saw higher than normal temperatures (highest in in the last 100 years) and there were numerous cloudbursts in Jammu and Kashmir.
- A strong upper-atmospheric high was located over European Russia towards the beginning of summer.
- It diverted the jet stream (meandering of Sub-Tropical Jet Stream) and its rain-giving train (trough) of summer storms farther north than usual, giving much of Southern European Russia drought conditions.

- In addition, southern desert heat from central Asia, the Arabian Peninsula and North Africa began to flow northward, which strengthened this ridge of STJ and tightened its hold over the region.



- The stalled system prevented weather systems being drawn across Russia and the obstacle acted as a barrier **trapping hot air to the south and cold air to the north**.

- The consequence of this static mass of hot air was the heat wave that devastated Russia.
- With the jet stream stalled the Sub-Tropical Jet was unable to transit across the Himalayas as it would do ordinarily, the monsoon cell to the south, fed by warmer waters in the Indian Ocean, had nowhere to go and as a consequence it deposited vast amounts of rain over Pakistan, Himalchal Pradesh and Jammu and Kashmir and this led to extensive flooding.

Indian Climate – Climate of India – Features of Indian Climate – Factors Influencing The Climate Of India: Physiography, Monsoon Winds, El Nino etc..

What type of Climate Does India Have?

- India's climate closely resembles the climate that of a tropical country although its northern part (north of tropic of cancer) is situated in the **temperate belt.**
- Indian subcontinent is separated from the rest of Asia by the **lofty Himalayan ranges** which block the **cold air masses** moving southwards from Central Asia.
- As a result, during winters, the northern half of India is warmer by **3°C to 8°C** than other areas located on same latitudes.
- During summer, due to over the head position of the sun, the climate in the southern parts resemble equatorial dry climate.
- The north Indian plains are under the influence of hot dry wind called **'loo'** blowing from the **Thar, Baloch and Iranian Deserts**, increasing the temperatures to a level comparable to that of the southern parts of the country.
- Thus the whole of India, south of the Himalayas can be climatically treated as a tropical country.
- The seasonal reversal of winds in Arabian Sea and Bay of Bengal give India a typical **tropical monsoon climate.**
- So Indian climate, to be precise, is **tropical monsoon type (a distinct wet and dry climate)** rather than just a tropical or half temperate climate.

Features of Indian Climate

- India has high Regional Climatic Diversity because of its topographical diversity (location, altitude, distance from sea and relief).

Rainfall

- The climate in most of the regions is characterized by **distinct wet and dry seasons**. Some places like Thar desert, Ladakh have no wet season.
- Mean annual rainfall varies substantially from region to region. **Mawsynram and Cherrapunji** in Meghalaya receives around 1,000 cm of annual rainfall while at Jaisalmer the annual rainfall rarely exceeds 12 cm.
- The Ganga delta and the coastal plains of Odisha see intense rainfall in July and August while the Coromandel Coast goes dry during these months.
- Places like Goa, Hyderabad and Patna receive south-west monsoon rains by the first quarter of June while the rains are awaited till early July at places in Northwest India.

Temperature

- Diurnal and annual temperature ranges are substantial.
- Highest diurnal temperature ranges occur in the Thar desert and the highest annual

temperature ranges are recorded in the Himalayan regions.

- Both diurnal and mean annual temperature ranges are least in coastal regions.
- In December, the temperature may dip to – 40°C at some places in J&K while in many coastal regions average temperature is 20-25°C.
- Winters are moderately cold in most of the regions while the summers are extremely hot.
- Himalayan regions experience brutal winters while the summers are moderate.

Factors Influencing Indian Climate

- Latitudinal location
- Distance from the Sea
- The Himalayas
- Physiography
- Monsoon Winds
- Upper Air Circulation
- El Nino and La Nina
- Tropical Cyclones and Western Disturbances

Latitudinal location

- The mainland of India extends between **8°N to 37°N.**
- Areas south of the Tropic of Cancer are in tropics and hence receive high solar insolation. The summer temperatures are extreme and winters temperatures are moderate in most of the regions.
- The northern parts on the other hand lie in the warm temperate zone. They receive comparatively less solar insolation. But summer are equally hot in north India because of hot local wind called **'loo'**. Winter are very cold due to cold waves brought by the **western disturbances.**
- Some places in Himalayas record low temperatures particularly in winter.
- Coastal regions see moderate climatic conditions irrespective of latitudinal position.

Distance from the Sea

- Coastal regions have moderate or equable or maritime climate where as interior locations are deprived of the moderating influence of the sea and experience extreme or continental climate.
- The monsoon winds first reach the coastal regions and hence bring good amount of rainfall.

Himalayas

- The Himalayas act as a **climatic divide** between India and Central Asia.
- During winter, Himalayas **protect India from cold and dry air masses of Central Asia.**
- During monsoon months these mountain ranges act as an **effective physical barrier for rain bearing south-west monsoon winds.**
- **Himalayas divide the Bay of Bengal branch of monsoon winds into two branches – one branch flowing along the plain regions towards north-west India and the other towards South-East Asia.**
- If the Himalayas were not present, the monsoon winds would simply move into China and most of the north India would have been a desert.

Why rainfall decreases form east to west in plains region (Indus-Ganga Plains)?

- In summer, there are many minor low pressure cells that exist all over the plain region.
- As the monsoon winds move from east to west the moisture levels decrease due to successive rainfall at each low pressure regions.
- By the time winds reach western parts of the plains (Delhi, Haryana etc.) all the moisture in the monsoon winds in **exhausted.**

Then how come Haryana and Punjab not deserts like Rajasthan?

- They receive rainfall due to Western Disturbances in winter. (In summer the rainfall is very low.)

Physiography

- Physiography is the most important factor that determines the mean annual rainfall received by a region.

Why are some parts in peninsular India semi-arid?

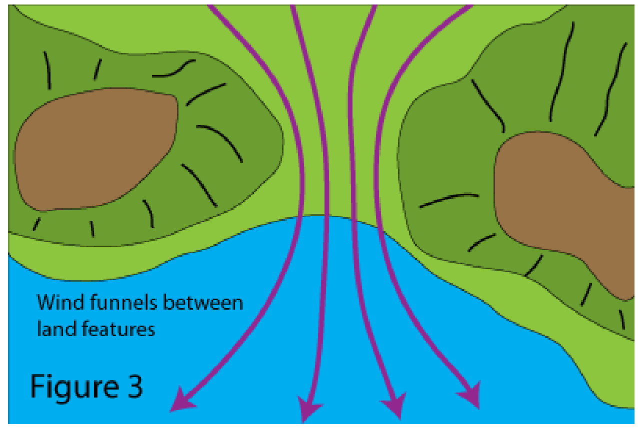
- Places on the windward side of an orographic barrier receive great amount of rainfall where as those on the leeward side remain arid to semi-arid due to **rain-shadow effect.**
- Example: The south-west monsoon winds from the Arabian sea strike almost **perpendicular** at the Western Ghats and cause copious rainfall in the Western Coastal plain and the western slopes of the Western Ghats.
- On the contrary, vast areas of Maharashtra, Karnataka, Telangana, Andhra Pradesh and Tamil Nadu lie in rain-shadow or leeward side of the Western Ghats and receive scanty rainfall.

Why no significant rainfall in Gujarat and Rajasthan? Explain the formation of Thar Desert?

- Monsoons winds flowing in Rajasthan and Gujarat are **not obstructed by any orographic barrier** and hence these regions receive no rainfall.
- [Monsoon winds blow almost parallel to Aravalis and hence there is no orographic rainfall].
- [No convection cell or vertical wind movements arise in Rajasthan and Gujarat: Monsoon winds blow towards low pressure cells in Tibet and hence only horizontal wind movements exist in Gujarat and Rajasthan]
- [Sub-tropical high pressure belt: In winter the region experiences strong divergence because of the STJ – Sub-Tropical Jet.]

How come Cherrapunji and Mawsynram receive abnormally high rainfall?

- **Mawsynram** and **Cherrapunji** are the wettest places on earth with mean annual rainfall over 1000 cm.
- Copious rainfall in these places is due to **funneling effect** followed by **orographic upliftment.** [Funneling effect = clouds are channeled into a narrow region between mountains and hence the cloud density is extraordinary]



Monsoon Winds

- The most dominating factor of the Indian climate is the 'monsoon winds'.

Important features of Indian Monsoons are

1. **Sudden onset (sudden burst)**
2. **Gradual progress**
3. **Gradual retreat**
4. **Seasonal reversal of winds**

- The complete reversal of the monsoon winds brings about a **sudden change in the seasons.**
- The harsh summer season suddenly giving way to monsoon or rainy season.
- The south-west monsoons from the Arabian sea and the Bay of Bengal bring rainfall to the entire country.
- The north-eastern winter monsoon do not cause much rainfall except along the Caromandel coast (TN coast) after getting moisture from the Bay of Bengal.

Upper Air Circulation

- The changes in the upper air circulation over Indian landmass is brought about by Jet streams. **(Explained in detail in Indian Monsoons)**

Westerly Jet Stream

- Westerly jet stream blows at a very high speed during winter over the **sub-tropical zone.**
- Southern branch of the jet stream exercises a significant influence on the winter weather conditions in India.
- This jet stream is responsible for bringing **western disturbances** from the Mediterranean region in to the Indian sub-continent.
- Winter rain and heat storms in north-western plains and **occasional heavy snowfall** in hilly regions are caused by these disturbances.
- These are generally followed by cold waves in the whole of northern plains.

Easterly Jet Stream

- Reversal in upper air circulation takes place in summer due to the apparent shift of the sun's vertical rays in the northern hemisphere.
- The westerly jet stream is replaced by the easterly jet stream which owes its origin to the heating of the Tibet plateau.
- This helps in the **sudden onset of the south-west monsoons**.

Tropical Cyclones and Western Disturbances

- Tropical cyclones originate in the Bay of Bengal and Arabian Sea and the influence large parts of the peninsular India.
- Majority of the cyclones originate in the **Bay of Bengal** and influence the weather conditions during the south-west monsoon season **(low intensity cyclones).**
- Some cyclones are born during the retreating monsoon season, i.e., in October and November **(high intensity cyclones)** and influence the weather conditions along the eastern coast of India.
- The western disturbances originate over the Mediterranean sea and travel eastward under the influence of westerly jet stream.
- They influence the winter weather conditions over most of Northern-plains and Western Himalayan region.

El-Nino, La Nina and ENSO

El Nino

- Adversely affects monsoon rainfall and cyclogenesis in Bay of Bengal.
- Good for cyclogenesis in Arabian Sea.
- Droughts are common during El Nino events due to less monsoonal and cyclonic rainfall.

La Nina

- Good for monsoons and cyclogenesis in Bay of Bengal.
- Suppressed cyclogenesis in Arabian Sea.
- Floods are common.

ENSO

- Southern Oscillation is simply the oscillation or alternating positions of low pressure and high pressure cells over eastern and western Pacific.
- Southern Oscillation coinciding with El Nino is called ENSO or El Nino Southern Oscillation. (SO usually coincides with EL Nino. This why El Nino is usually referred to as ENSO)
- ENSO = [warm water in eastern Pacific + low pressure over eastern Pacific] + [cool water in western Pacific + high pressure in western Pacific]
- Climatic conditions same as El Nino.

Winter Season – Summer Season – Indian Climate: Pressure, Winds, Rainfall, Temperature, Cyclones, Western Disturbances. Loo, Andhis, Norwesters, Thunderstorms, etc..

Indian Climate – Seasons

- The cold weather season or winter season,

- The hot weather season or summer season,
- The south-west monsoon season or Rainy season, and
- The season of the retreating monsoon or cool season.

Winter Season in India

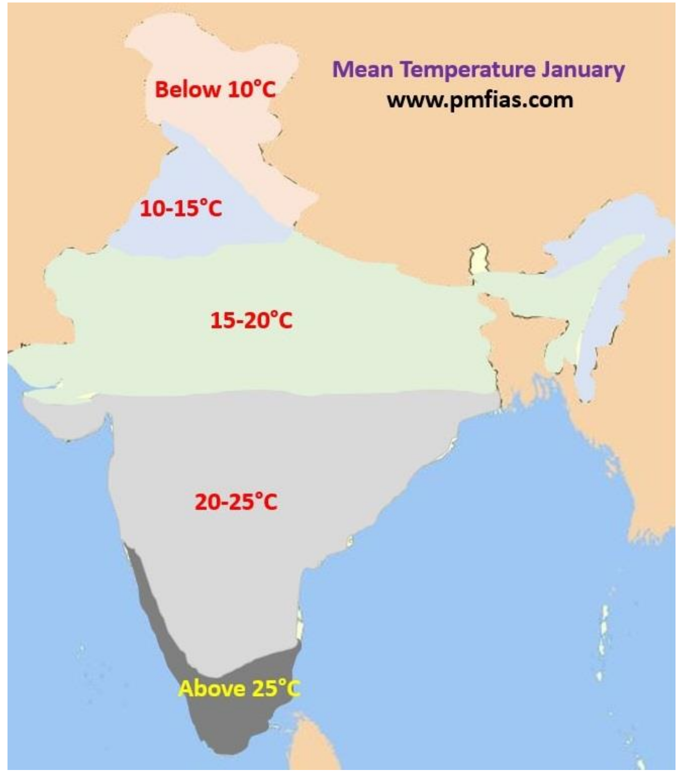
- **November – March. January** is the coldest month.
- Sun's apparent path is to the south of equator.
- **Clear sky, pleasant weather, low temperature, low humidity, high range of temperature, cool and slow north-east trade winds.**
- The diurnal range of temperature, especially in interior parts of the country, is very high.

Temperature in Winter Season

- The isotherm of 20°C runs roughly parallel to the Tropic of Cancer.
- To the south of this isotherm the temperatures are above 20°C. Here there is no distinctly defined winter weather. Some parts of Kerala and Tamil Nadu typically experiences temperatures near 30°C.
- To the north mean temperatures are below 21°C and the winter weather is distinct.
- The mean minimum temperature is about 5°C over north-west India and 10°C over the Gangetic plains.
- **Dras Valley** in Kashmir is the coldest place in India. The minimum temperature recorded at Dras was – 45°C in 1908.

Pressure in Winter Season

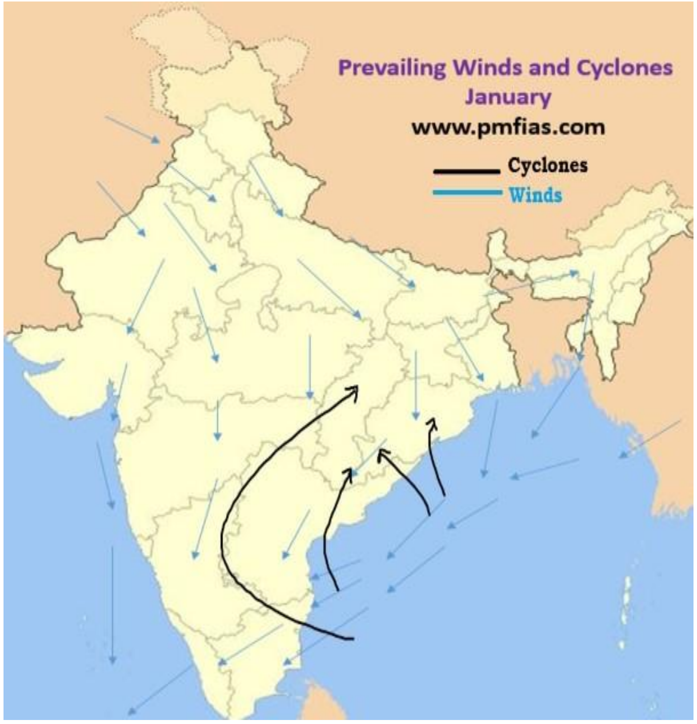
- High air pressure prevails over large parts of north-west India due to low temperatures coupled with divergence induced by the ridge of the STJ.
- Pressure is comparatively lower in south India.



- The winds start blowing from high pressure area of north-west to low pressure area of south-east. The wind velocity is low due to low pressure gradient.
- The path of the winds depend on pressure gradient and physiography.

Western Disturbances in Winter Season

- The spell of fine weather over north-western and northern India is often broken due to inflow of western disturbances.
- They intensify over Rajasthan, Punjab, and Haryana.
- They move eastwards across the sub-Himalayan belt up to Arunachal Pradesh.
- They cause light rain in the Indus-Ganga plains and snowfall in the Himalayan belt.
- After the passage of the disturbance, widespread fog and cold waves lowering the minimum temperature by **5° to 10°C** below normal are experienced.
- Fog lowers visibility and causes great inconvenience for transportation.



Tropical Cyclones in Winter Season

- This is the season of least tropical cyclone activity.
- The frequency of tropical cyclones decreases with the advancement of the season.
- This is due to **low sea surface temperature and exit of ITCZ farthest south.**
- The storms which are born in the Bay of Bengal strike Tamil Nadu and bring heavy rainfall.
- Some of them cross the southern peninsula over to the Arabian Sea.
- Some storms originate in the Arabian Sea and move towards either north or west.

Precipitation in Winter Season

- The retreating winter monsoons pick up some **moisture while crossing the Bay of Bengal and cause winter rainfall in Tamil Nadu, south Andhra Pradesh, south-east Karnataka and south-east Kerala (Usually in the first weeks of November).**
- The highest seasonal rainfall of about 75 cm between October and December.
- Most of it occurs along the south-eastern coast of Tamil Nadu and adjoining parts of Andhra Pradesh. Thereafter, it gradually decreases.
- The western disturbances also cause a little rainfall in north-west India.
- The amount of rainfall gradually decreases from the north and north-west to east (it is opposite in rainy season).
- The northeastern part of India also gets rainfall during the winter months.

Summer Season in India

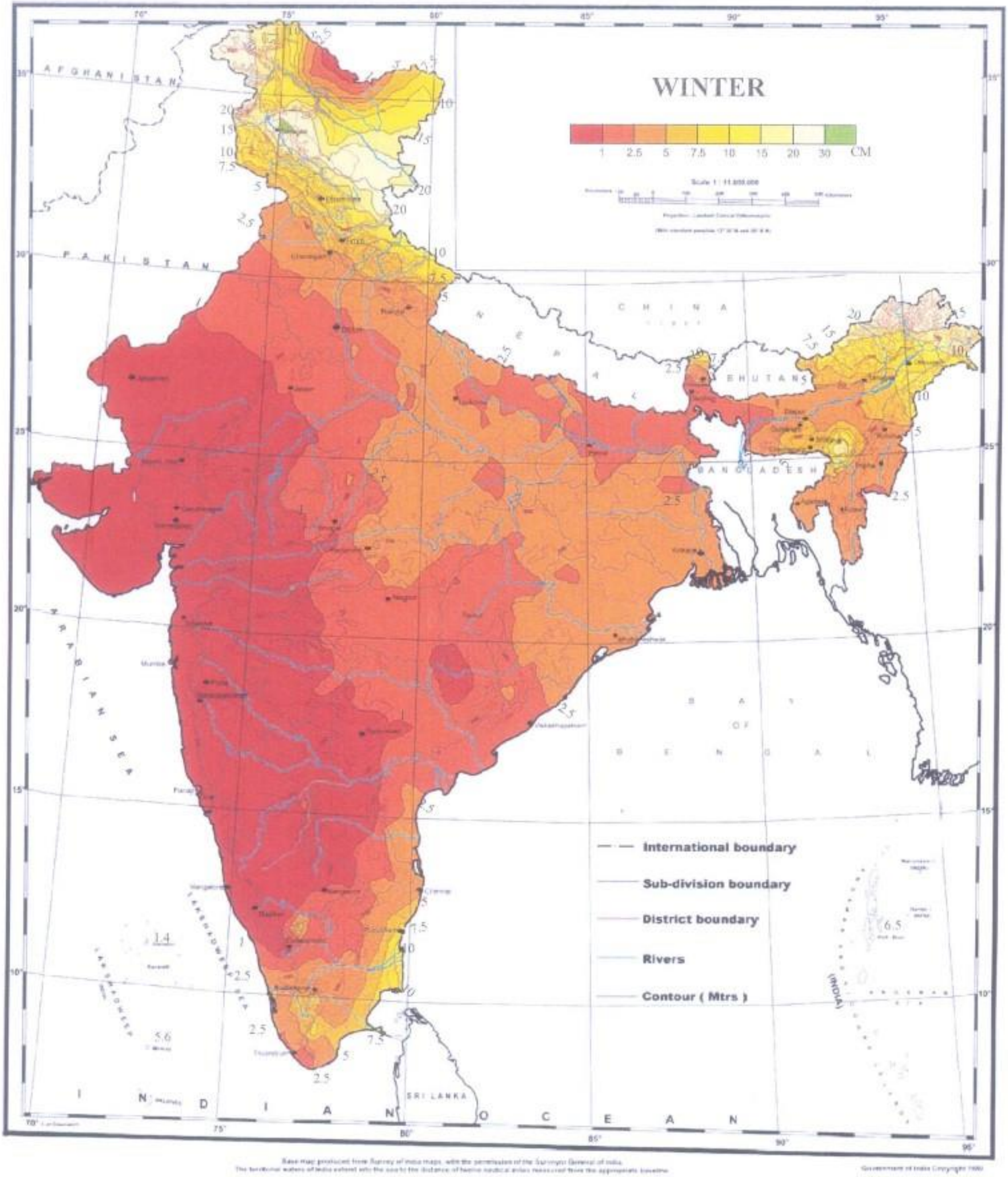
- **March to June**.
- High temperature and low humidity are the chief characteristics.
- Sometimes referred to as **pre-monsoon period.**

Temperature in Summer Season

- High sun's insolation due to apparent movement of sun between the equator and the Tropic of Cancer.
- The southern parts of the country are distinctly warmer in March and April whereas in June, north India has higher temperatures.
- In March, the highest temperatures occur in the southern parts (40-45°C).
- In April the highest temperature of about 45°C is recorded in the northern parts of Madhya Pradesh.
- In May the highest temperature shifts to Rajasthan where temperatures as high as 48°C may be recorded.
- In June the maximum temperature is in Punjab and Haryana.
- The highest temperatures recorded are **50.5°C at Alwar** on 10th May, 1956 and **50.6°C at Ganganagar** on 14th June, 1935.
- The highest temperatures are recorded just before the onset of the southwest monsoons (late May).
- The diurnal range of temperature is also very high. It may be as high as 18°C in some parts.
- The maximum summer temperatures are comparatively lower in the costal and southern peninsular regions due to moderating effect of the sea.

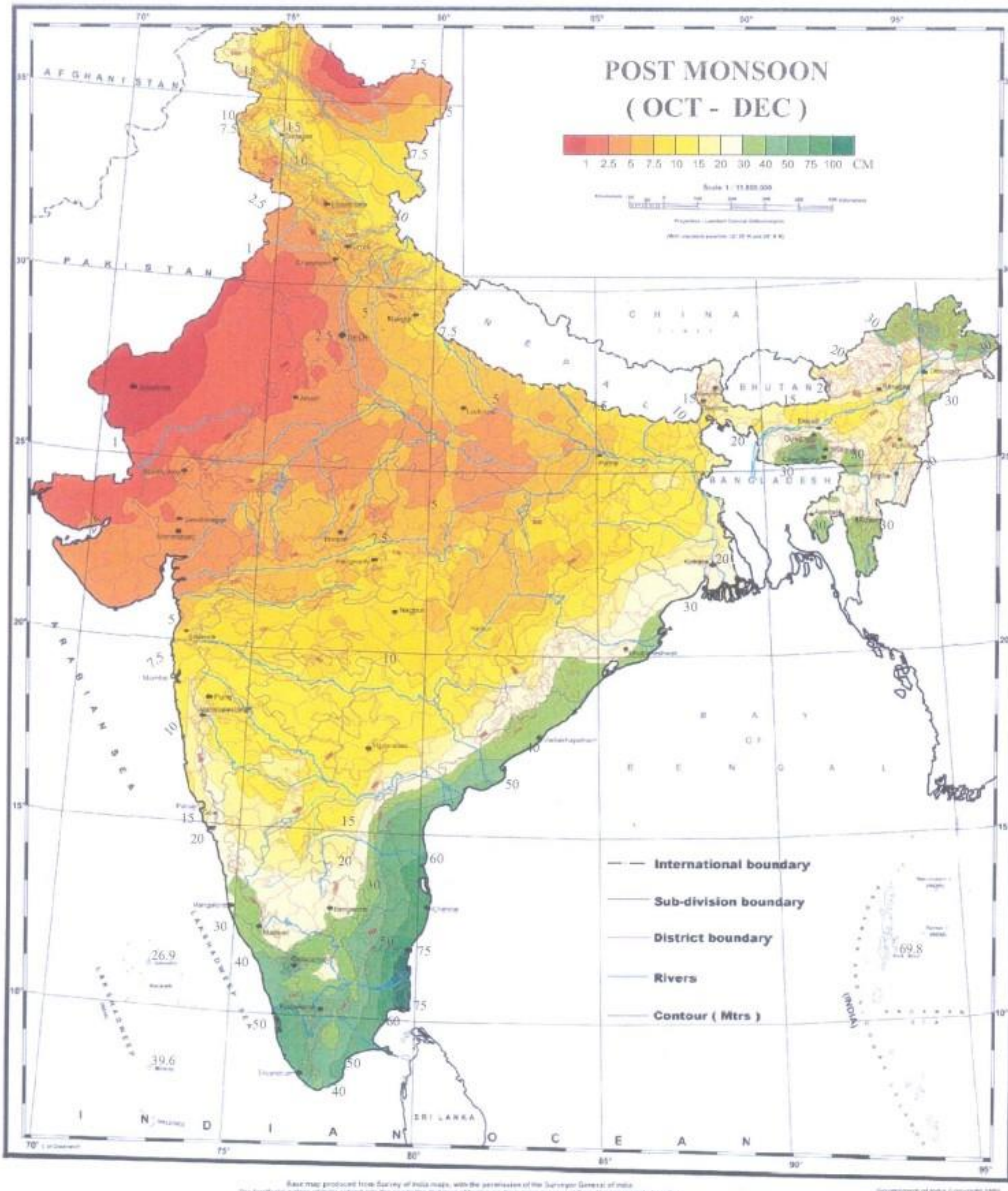
RAINFALL (cm)

Map No.37



RAINFALL (cm)

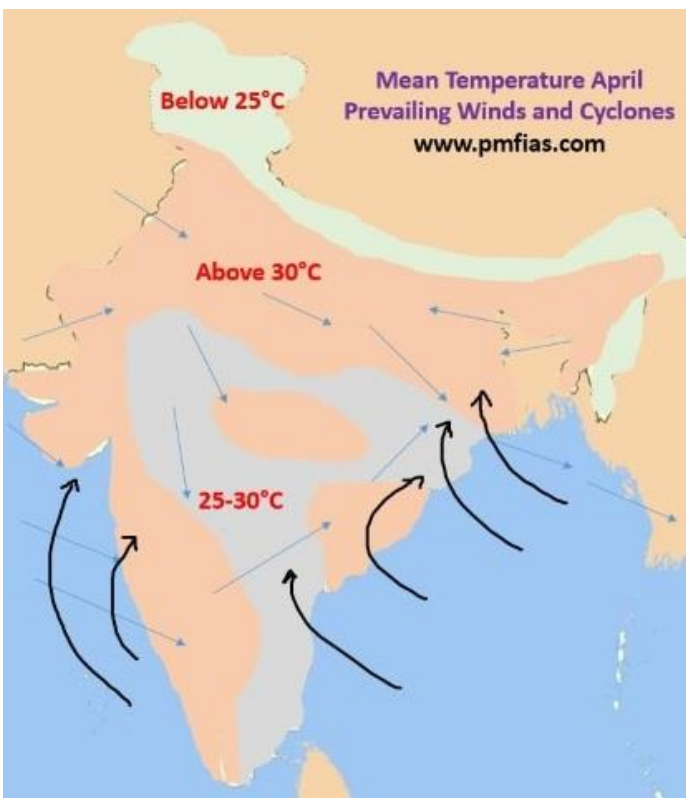
Map No. 46



- The temperatures along the west coast are comparatively lower than those prevailing on the east coast due to the prevailing westerly winds.
- There is large contrast between land and sea temperatures.
- Northern and central parts of India experience heat waves in this season.

[A heat wave is an abnormally high temperature experienced by a regions. Temperature increase of the order of 6° to 7°C above normal is termed as 'moderate' and 8°C and more as 'severe' heat wave]

- Most of the heat waves develop over Rajasthan, Punjab and Haryana (location far away from the sea). From here they spread over Uttar Pradesh and Bihar.
- The strong north westerly winds (caused due to strong divergence in north-west India) with a long land journey over hot regions check the onward march of the sea breeze over eastern coastal belt and create heat wave conditions over Odisha and Andhra Pradesh.
- The heat waves strike by the end of April and their maximum occurrence is in May. They last till the onset of southwest monsoon.
- The normal duration of heat waves is 4 to 5 days. However, heat waves are rare over the peninsula south of 13°N latitude due to maritime conditions prevailing there.



Pressure in Summer Season

- The atmospheric pressure is low all over the country due to high temperature.
- But strong dynamically induced divergence over north-west India prevents the onset of south-west monsoons.

Winds in Summer Season

- There is a marked change in the direction and speed of the winds from winter.
- The winds are by and large light and variable.

Loo

- Loo winds originate over **Iranian, Baloch and Thar deserts.**
- In May and June, high temperature in northwest India builds steep pressure gradient.
- Hot, dust laden and strong wind known as loo blows.
- Loo normally starts blowing by 9.00 A.M., increases gradually and reaches maximum intensity in the afternoon.
- It blows with an average speed of 30-40 km per hour and persists for days.

Andhis

- The strong dust storms resulting from the convective phenomena are locally known as **andhis (blinding storms).** They move like a solid wall of dust and sand.
- The wind velocity often reaches 50-60 kmph and the visibility is reduced to a few metres.
- Such dust storms are common in Rajasthan, Haryana, Punjab, Jammu region, Delhi, Uttar Pradesh, Bihar and Madhya Pradesh.
- They are short lived. The squall and showers which follow these storms bring down the temperature sharply temporarily.

Frontal Thunderstorms in Summer Season

- The strong convectional movements related to the westerly jet stream lead to thunderstorms in eastern and north-eastern part of the country.

- They normally originate over Chota Nagpur plateau and are carried eastwards by westerly winds.
- The areas with highest incidence of thunderstorms are *Assam, Arunachal Pradesh, Nagaland, Mizoram, Manipur, Tripura, Meghalaya, West Bengal and the adjoining areas of Odisha and Jharkhand.*

Norwesters and Thunderstorms in Summer Season

- In West Bengal and the adjoining areas of Jharkhand, Odisha and Assam, the direction of squalls is mainly from the northwest, and they are called **norwesters.**
- They are often very violent with squall speeds of 60 to 80 km per hour.
- Hailstones sometimes accompany showers and occasionally attain the size of a golf ball.
- They cause heavy damage to standing crops, trees, buildings, livestock and even lead to loss of human lives.
- However, they are, sometimes, useful for tea, jute and rice cultivation. In Assam, these storms are known as **'Barodoli Chheerha'.**
- The period of maximum occurrence of these storms is the month of Vaisakh (mid-March to mid-April) and hence, they are locally known as **Kalabaisakhis,** the black storms or a mass of dark clouds of Vaiasakha.

Convectional Thunderstorms in Summer Season

- In the south the thunderstorms occur in **Kerala (Mango Showers)** and adjoining parts of **Karnataka (Blossom Showers)** and Tamil Nadu, particularly during evenings and nights.

Western Disturbances in Summer Season

- Their frequency and intensity gradually decrease with advancement of summer.
- Approximately 4, 3 and 2 western disturbances visit north-west India in March, April and May respectively.
- They cause snowfall in higher reaches of the Himalayas.

Tropical Cyclones in Summer Season

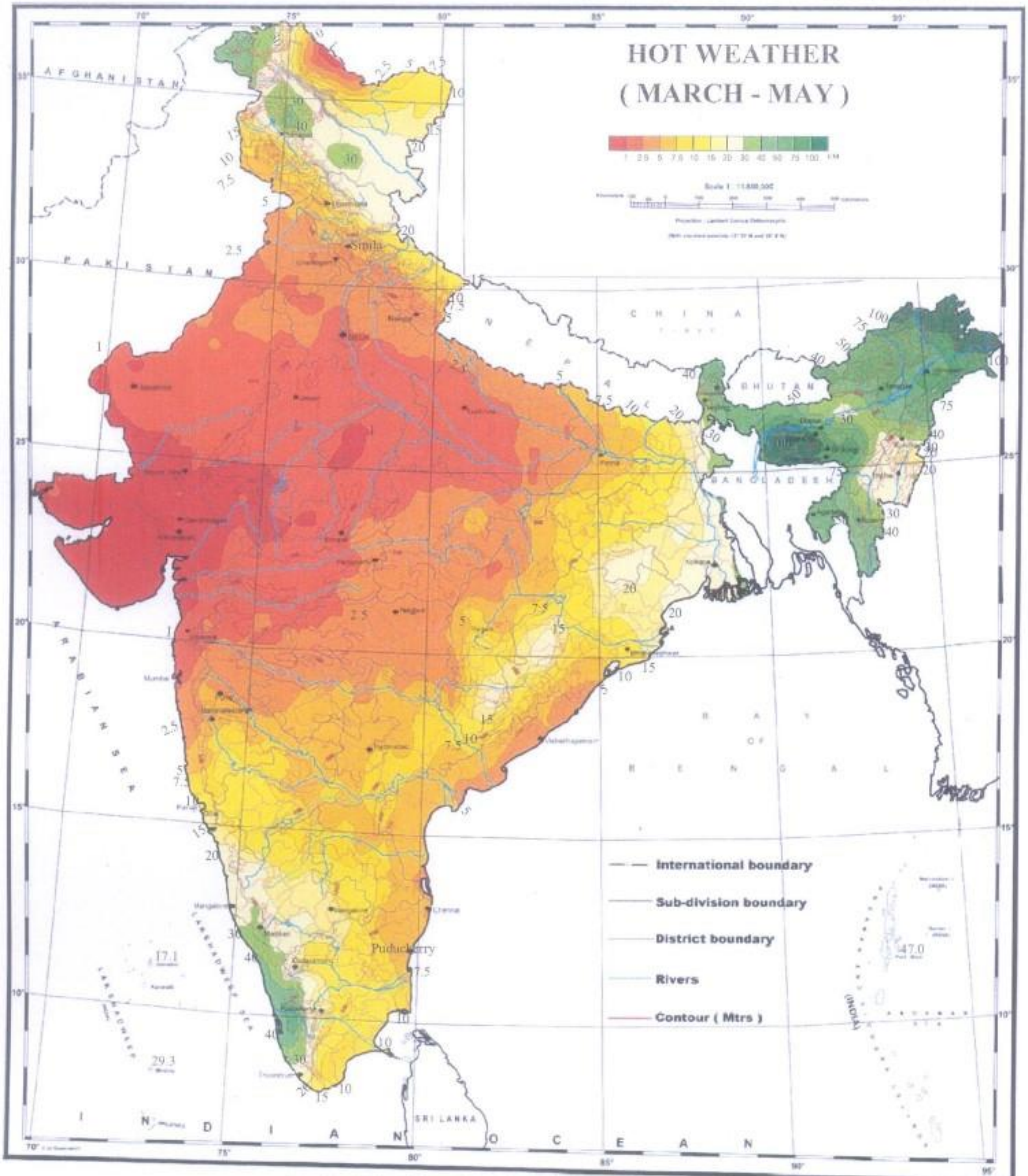
- Tropical cyclones originate in the Bay of Bengal and Arabian Sea.
- A few cyclones are formed in the Bay of Bengal in the month of March but they do not affect the mainland of India.
- Their frequency rises steeply in April and the number of cyclones originating in May is more than double than those originating in April.
- About three-fourths of the tropical cyclones are born in the Bay of Bengal and the rest originate in the Arabian Sea.
- Most of the depressions in April originate to the south of 10°N while those originating in May are born to the north of this latitude.
- Most of the storms of this season initially move west or north-west but later they recurve northeast and strike **Bangladesh and the Arakan Coast of Myanmar.**
- Very few hit Indian coast while some dissipate over the sea itself.
- The whole of the east coast of India, the coastal areas of Bangladesh and Arakan Coast of Myanmar are liable to be hit by tropical storms in May.
- Many of them are quite severe and cause heavy damage to life and property.
- In the Arabian Sea, major storms are formed in May between 7° and 12° N latitudes.
- Most of them move away from the Indian coast in a north-westerly direction and dissipate in the sea.
- Few originate close to the Indian coast. They move towards the north-east and hit somewhere along the west coast of India.

Precipitation in Summer Season

- This season is not totally rainless (only one per cent of the annual rainfall).

RAINFALL (cm)

Map No. 40



- In the northeastern parts of the country, dust storms bring little rainfall.
- The precipitation in Kashmir is mainly in the form of snow caused by western disturbances.

- The norwesters bring some rainfall in Assam, West Bengal and Odisha. The intensity of rainfall is high.
- The rainfall brought by the norwesters is known as the **spring storm showers.**
- This small amount of rainfall is very useful for the cultivation of tea, jute and rice and is known as **tea showers in Assam.**
- Coastal areas of Kerala and Karnataka receive rainfall from thunderstorms.
- Such showers are called **mango showers** in Tamil Nadu and Andhra Pradesh because they are very beneficial to mango crop.
- In Karnataka they are called **cherry blossoms** due to their effect on the coffee plantations.

Rainy Season – South West Monsoon Season – North East Monsoon Season

ISOLINE: imaginary lines joining regions with equal rainfall or any other parameter.

ISOBAR: imaginary lines joining regions with equal pressure.

ISOTHERM: imaginary lines joining regions with equal temperature.

ISOHYET: imaginary lines joining regions with equal rainfall.

Rainy Season – South West Monsoon Season

- South West Monsoon Season – **June to mid-September.**
- South West Monsoon Season is also known as **hot-wet season.**
- Sudden onset is the important feature of South West Monsoons.
- With the onset of monsoons, temperature falls drastically and humidity levels rise.

Temperature during South West Monsoon Season

- Sudden onset of South West Monsoons leads to significant fall in temperature [3° to 6°C].
- The temperature remains less uniform throughout the rainy season.
- The temperature rises in September with the cease of south-west monsoons.
- There is rise in temperature whenever there is **break in the monsoons**.
- The diurnal range of temperature is small due to clouds and rains.
- The highest temperatures are experienced at places west of the Aravali [38° to 40°C]. This is due to lack of clouds and hot continental air masses.
- Other parts of Northwest India also have temperatures above 30°C.
- The temperatures are quite low over the Western Ghats due to heavy rainfall.
- The coastal areas of Tamil Nadu and adjoining parts of Andhra Pradesh have temperatures above 30°C as they receive little rainfall during this season.

Pressure and Winds During South West Monsoon Season

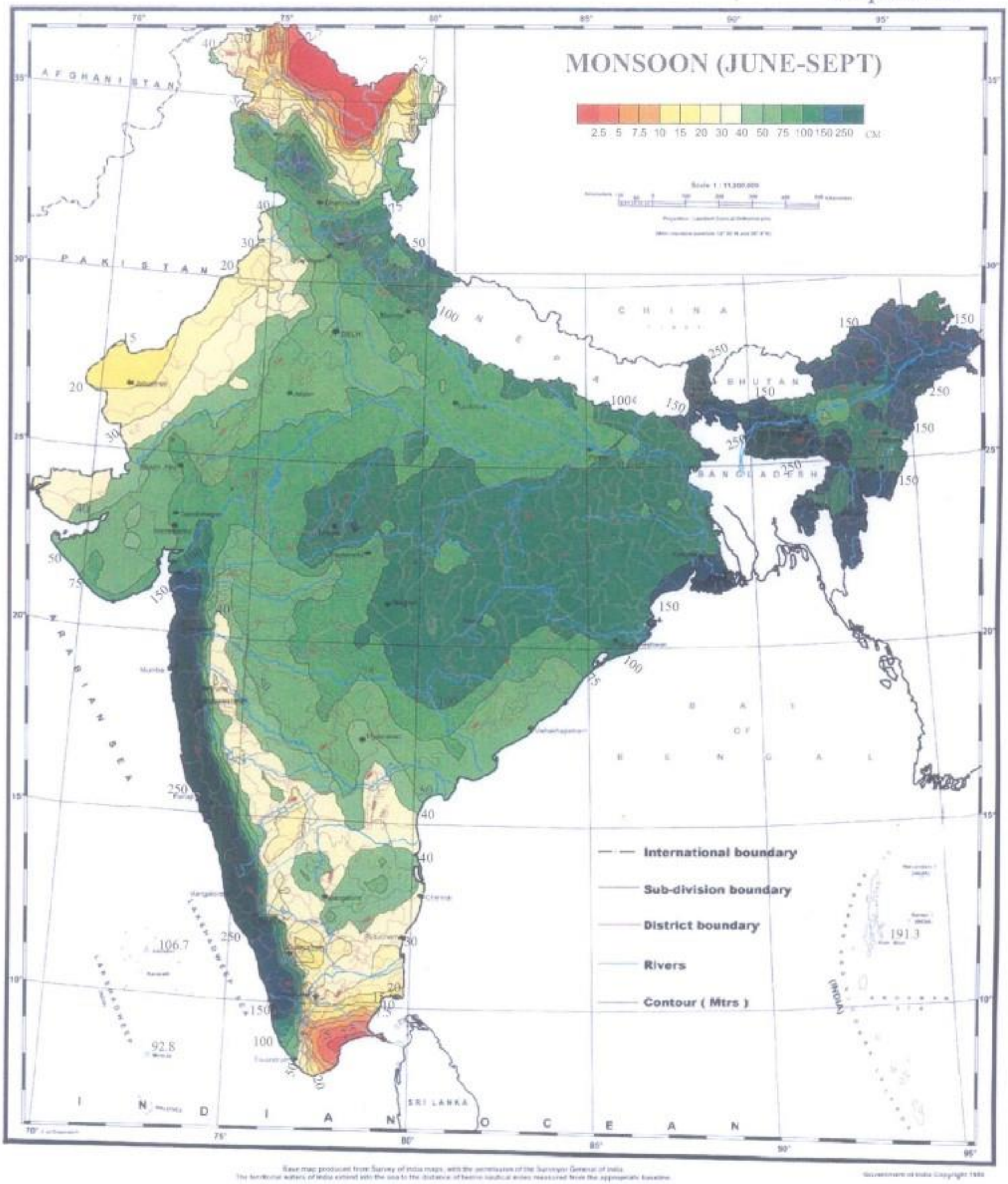
- Low pressure conditions prevail over northwest India due to high temperature.
- ITCZ (monsoon trough) lies along the Ganga plain. There are frequent changes in its location depending upon the weather conditions.
- The atmospheric pressure increases steadily southwards.
- Over the peninsular region, due to pressure gradient between north and south, winds blow in a southwest to northeast direction from Arabian sea and Bay of Bengal.
- Their direction undergoes a change in Indo-Gangetic plain where they move from east to west.

Rainfall During South West Monsoon Season

- Three fourths of the total annual rainfall is received during this season.
- The average rainfall over the plains of India in this season is about 87 per cent.
- Normal date of the arrival of the monsoon is 20th May in Andaman and Nicobar Islands.

RAINFALL (cm)

Map No. 43



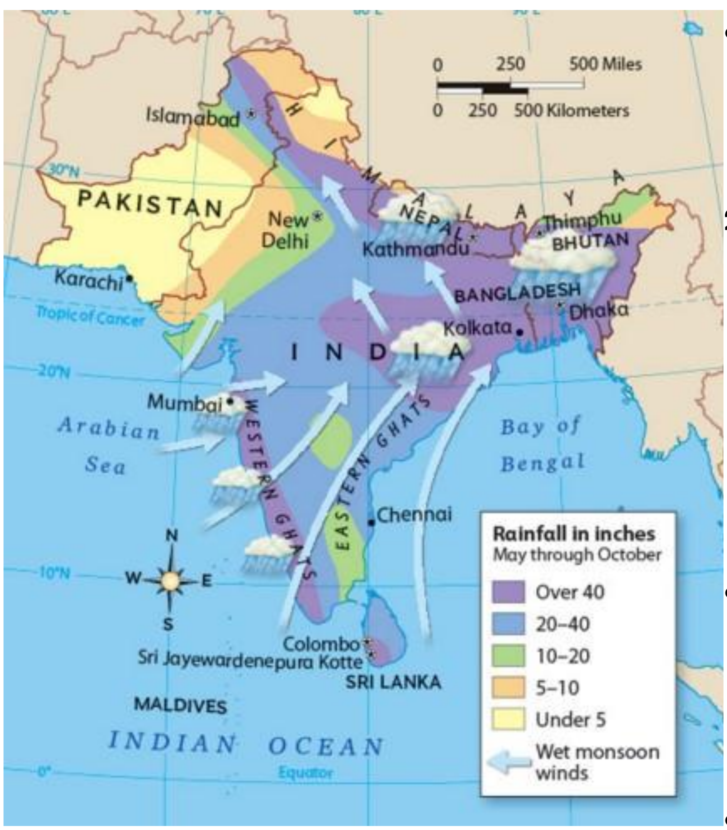
- The advance of the monsoon is **much faster in the Bay of Bengal than in the Arabian Sea.**
- The normal date of onset of the southwest monsoon over **Kerala i.e. the first place**

of entry in the mainland of India is 1st June.

- The monsoons advance quickly accompanied with a lot of thunder, lightning and heavy downpour. This sudden onset of rain is termed as **monsoon burst.**
- Sometimes monsoons are delayed or they come much earlier than normal.
- Normally the onset occurs between 29th May and 7th June.
- The earliest onset was on 11th May in 1918 and 1955, while the most delayed onset was on 18th June in 1972.

South West Monsoon – Arabian Sea branch and Bay of Bengal branch

- Monsoon winds beyond south Kerala progress in the form of two branches viz. the **Arabian Sea branch** and the **Bay of Bengal branch.**



- The Arabian Sea branch gradually advances northwards. It reaches Mumbai by 10th June.
- The Bay of Bengal branch spreads rather rapidly over most of Assam. The normal date of its arrival at Kolkata is 7th June.
- On reaching the foothills of the Himalayas the Bay branch is **deflected westward by the Himalayan barrier** and it advances up the Gangetic plain.
- The two branches merge with each other mostly **around Delhi** to form a single current.
- Both the branches reach Delhi more or less at the **same time**.
- The combined current gradually extends to west Uttar Pradesh, Haryana, Punjab, Rajasthan and finally to Himachal Pradesh and Kashmir.
- By the end of June the monsoon is usually established over most parts of the country.
- By mid-July, the monsoon extends into Kashmir and the remaining parts of the country.
- By this time it reaches Kashmir, it has **shed most of its moisture.**
- Arabian Sea branch of the monsoon is much powerful than the Bay of Bengal branch for reasons:

1. **The Arabian Sea is larger than the Bay of Bengal, and**
2. **the entire Arabian Sea current advances towards India, whereas only a part of the Bay of Bengal current enters India, the remainder proceeding to Myanmar, Thailand and Malaysia.**

The Arabian Sea branch of the southwest monsoons is divided into three distinct streams on arriving in the mainland of India.

- The first stream strikes the west coast of India and gives extremely heavy rainfall of over 250 cm. It strike perpendicular to Western Ghats causing plentiful Orographic Rainfall [400 to 500 cm annual rainfall on the windward side].
- Rainfall is drastically reduced to about 30-50 cm on the leeward side of the crest.
- There is a narrow belt of marked aridity on the immediate leeward side of the Western Ghats. But once it is passed, the air starts

rising again and the amount of rainfall increases further east.

- The second stream enters **Narmada—Tapi troughs (narrow rift valley)** and reaches central India. It does not cause much rain near the coast due to the absence of major orographic obstacle across the rift. Some parts of central India receive rainfall from this stream (Ex: Nagpur).
- The third stream moves parallel to the Aravali Range without causing much rainfall. Consequently the whole of Rajasthan is a desert area.
- However, some orographic effect is occurs on the south-eastern edge of the Aravali Range. **Mt. Abu** gets about 170 cm rainfall while the surrounding plains have only 60 to 80 cm rainfall.

The Bay of Bengal Branch of the southwest monsoon is divided into two distinct streams.

- The first stream crosses the **Ganga-Brahmaputra delta** and reaches **Meghalaya**. Here that the orographic effect results in intense rainfall. Cherrapunji receives an annual rainfall of 1,102 cm, major portion of which occurs from June to August.
- **Mawsynram (present champion)** located at 1,329 m above sea level just 16 km to the west of **Cherrapunji (X champion)** records higher annual rainfall of 1,221 cm.
- Both the stations are located on the southern slopes of the **Khasi hills** at the northern end of a deep valley running from south to north.
- The second stream of the Bay of Bengal branch moves along **Himalayan foothills** as they are deflected to the west by the Himalaya and brings widespread rainfall to Ganga plain.
- The rainfall by this stream is characterized by a **steady decline** as we move from east to west up the plain. [Previous Prelims Question]
- The **Tamil Nadu coast** remains relatively dry during the south-west monsoon period because of

1. **rain shadow effect of the Arabian Sea current and**
2. **Bay of Bengal current which flows parallel to the coast.**

Break in the South West Monsoons

- During the Monsoon season, there are periods when the Monsoon trough shifts to the foothills of Himalayas, which leads to sharp decrease in rainfall over most parts of the country but increase along the Himalayas and parts of Northeast India and Southern Peninsula.
- During July and August, there are certain periods when the monsoons become weak. Rainfall practically ceases over the country outside the Himalayan belt and southeast peninsula. This is known as **break in the monsoon.**
- Breaks are likely to occur during the second week of August and last for a week.
- The breaks are believed to be brought about by the northward shifting of the **monsoon trough (minimum low pressure cell in ITCZ).** The axis of the trough lies at the foothills of the Himalayas during the break period.

The monsoon trough is a portion of the Intertropical Convergence Zone as depicted by a line on a weather map showing the locations of minimum sea level pressure, and as such, is a convergence zone between the wind patterns of the southern and northern hemispheres.

- During the break period, heavy rainfall occurs over the sub-Himalayan regions and the southern slopes of the Himalayas.
- On an average one or two breaks do occur during the rainy season. 85 out of 100 years there is a break in the monsoons.

Depressions in South West Monsoon Season

- A major part of the South West Monsoon rainfall is generated by depressions [intense low pressure] originating in the

Arabian Sea and Bay of Bengal. Some depressions develop over land also.

- About 3-4 depressions are formed per month from June to September.
- Almost all of them are sucked inward through the deltas of great rivers [They need moisture to be alive], the Ganga, the Mahanadi, the Godavari, the Krishna and the Cauvery and cause heavy rain in these areas.
- The location of depressions strongly coincide with the latitudinal position of ITCZ.
- Most of the depression originate to the west of 90^{0} E in Bay of Bengal and move in north-west direction.
- In the Arabian Sea in June-July, the depressions move either in north-west or in northerly direction and may affect west Gujarat or Maharashtra.
- Storms during August and September are rare and are formed close to Maharashtra-Gujarat coast.
- Most of the rainfall in central and northern parts of the country is caused by these depressions.
- The absence of depressions or a change in their tracks result in deficit or no rain.

Chief Characteristics of South West Monsoon Rainfall

- Major part of monsoon rains are received between **June and September.**
- Monsoonal rainfall is largely governed by **relief and is orographic** in its mode.
- The amount of rainfall decreases with increasing distance from the sea.
- The rainless interval during south west monsoon season is known as 'breaks'. The breaks in rainfall are related to tropical cyclones which originate in the Bay of Bengal.
- There are large scale spatial variations in the distribution of rainfall.
- Monsoons often fail to keep date. Sometimes the monsoons withdraw before the scheduled time causing considerable damage to the crops.

North East Monsoon Season – Retreating Monsoon Season

- Starts with the beginning of the withdrawal of southwest monsoon [middle of September – November].
- The monsoons withdraw from the extreme north-west end of the country in September, from the peninsula by October and from the extreme south-eastern tip by December.
- In Punjab the south-west monsoons reach in the first week of July and withdraw from there in the second week of September.
- The south-west monsoons reach Coromandel coast in the first week of June and withdraw from there only in the middle of December.
- Unlike the sudden burst of the advancing monsoons, the **withdrawal is rather gradual** and takes about three months.

Advance and Withdrawal of South West Monsoons

Temperature during Retreating Monsoon Season

- With retreat of the monsoons, the clouds disappear and the sky becomes clear.
- The day temperature starts falling steeply.
- The diurnal range of temperature increases due to lack of cloud cover.

Pressure and Winds during Retreating Monsoon Season

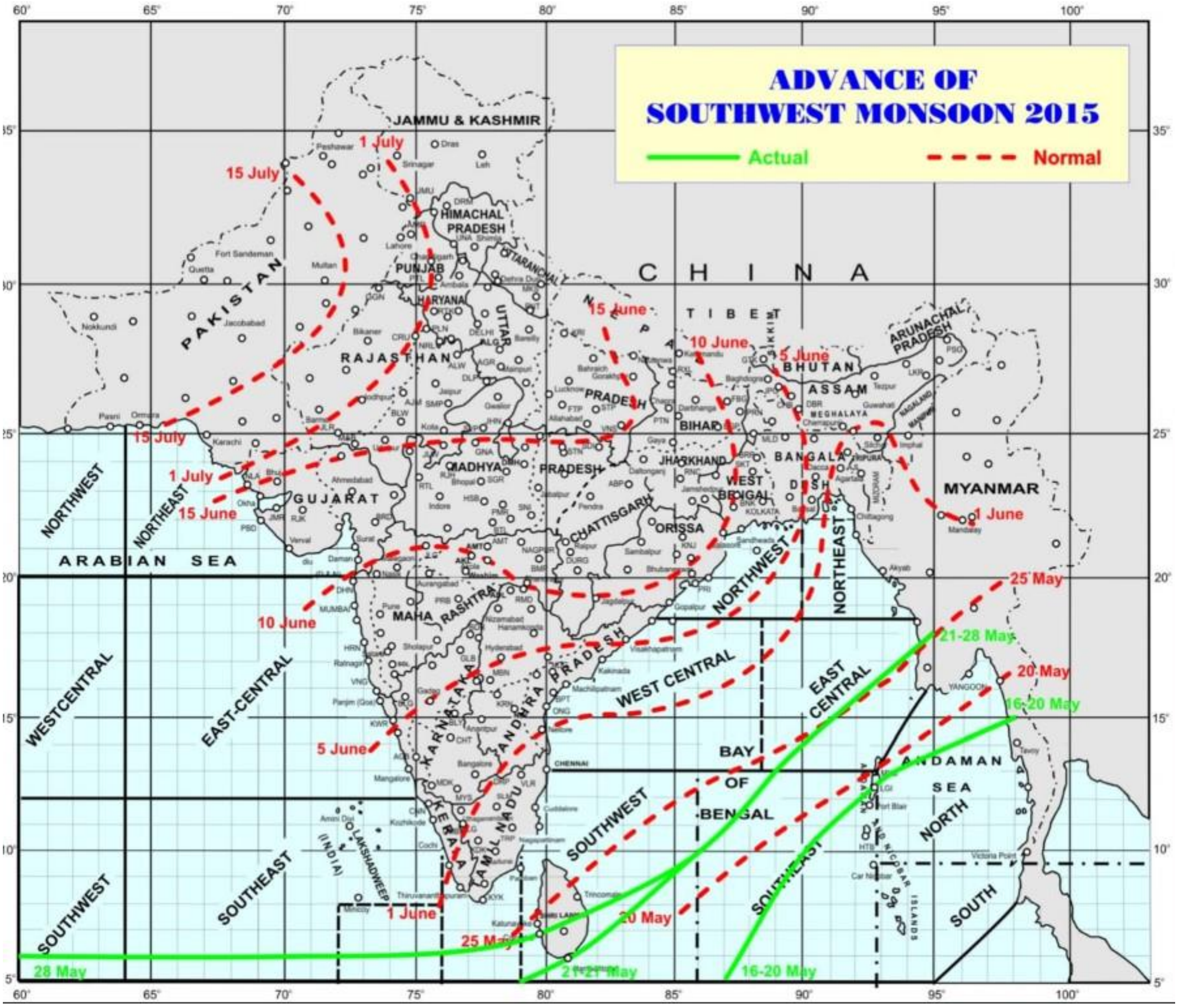
- As the monsoons retreat, the monsoon trough weakens and gradually shifts southward. Consequently the pressure gradient is low.
- Unlike south-west monsoon, the onset of the north monsoon is not clearly defined.
- The direction of winds over large parts of the country is influenced by the local pressure conditions.

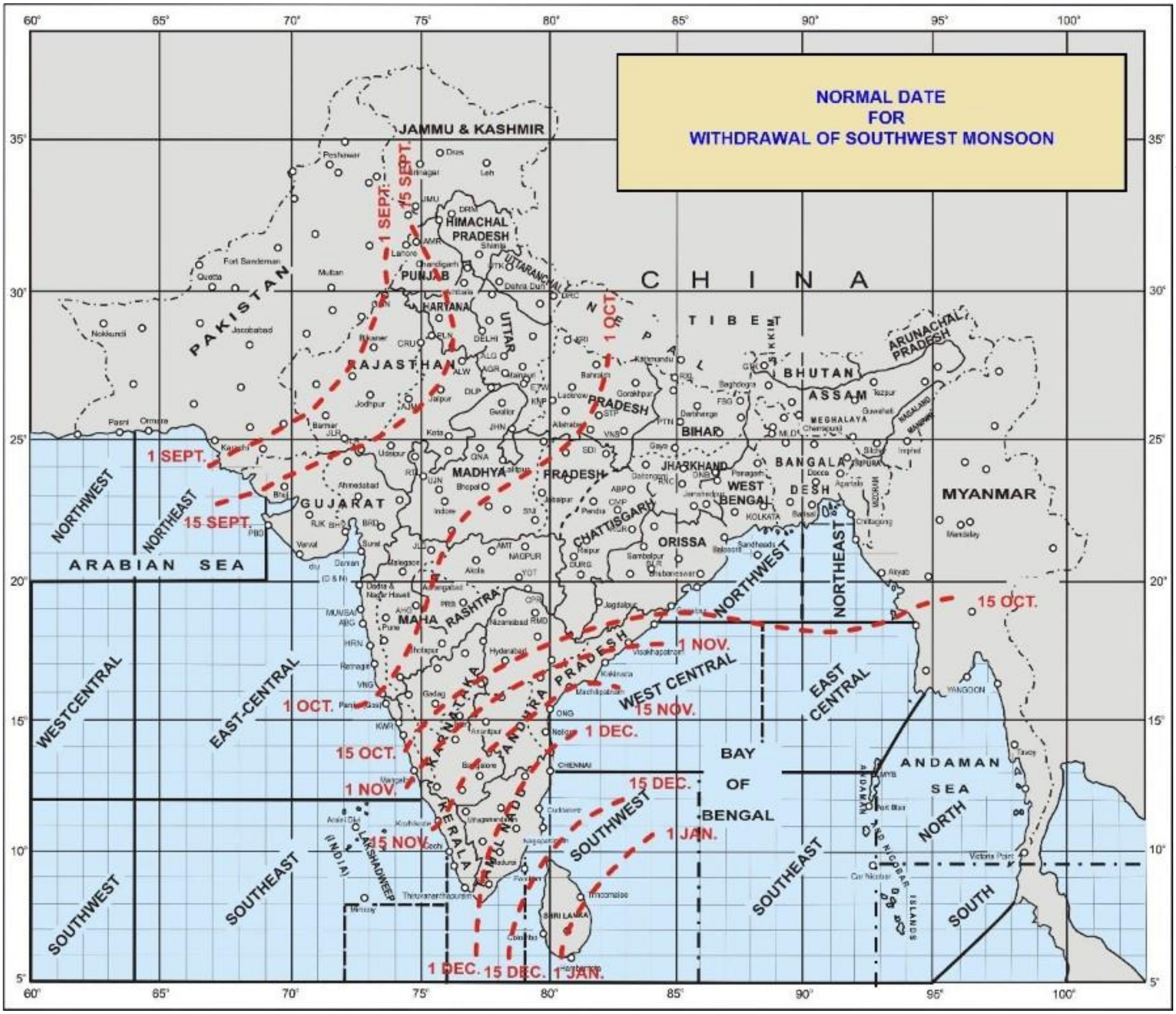
Cyclones during Retreating Monsoon Season

- **Most severe and devastating tropical cyclones** originate in the Indian seas especially in the Bay of Bengal.
- The highest frequency of the cyclones is in the month of October and the first half of November.

More cyclones are born in October and then in November and more cyclones originate in the Bay of Bengal than in the Arabian Sea.

- In October, the Cyclones of the Bay of Bengal originate between 8°N and 14°N.
- Initially they move in a west or northwesterly direction, but many of them later recurve and move towards the north-east.
- Near 55 per cent of the Bay storms cross or affect the Indian coast.
- The area's most vulnerable to these storms include the coastal belts of Tamil Nadu, Andhra Pradesh, Odisha and West Bengal.
- Many of the cyclones which strike the eastern coast of India, south of 15°N latitude cross the southern Peninsula and enter Arabian Sea.
- During this process, they may weaken, but on re-entry over the Arabian sea they intensify into cyclonic storms.





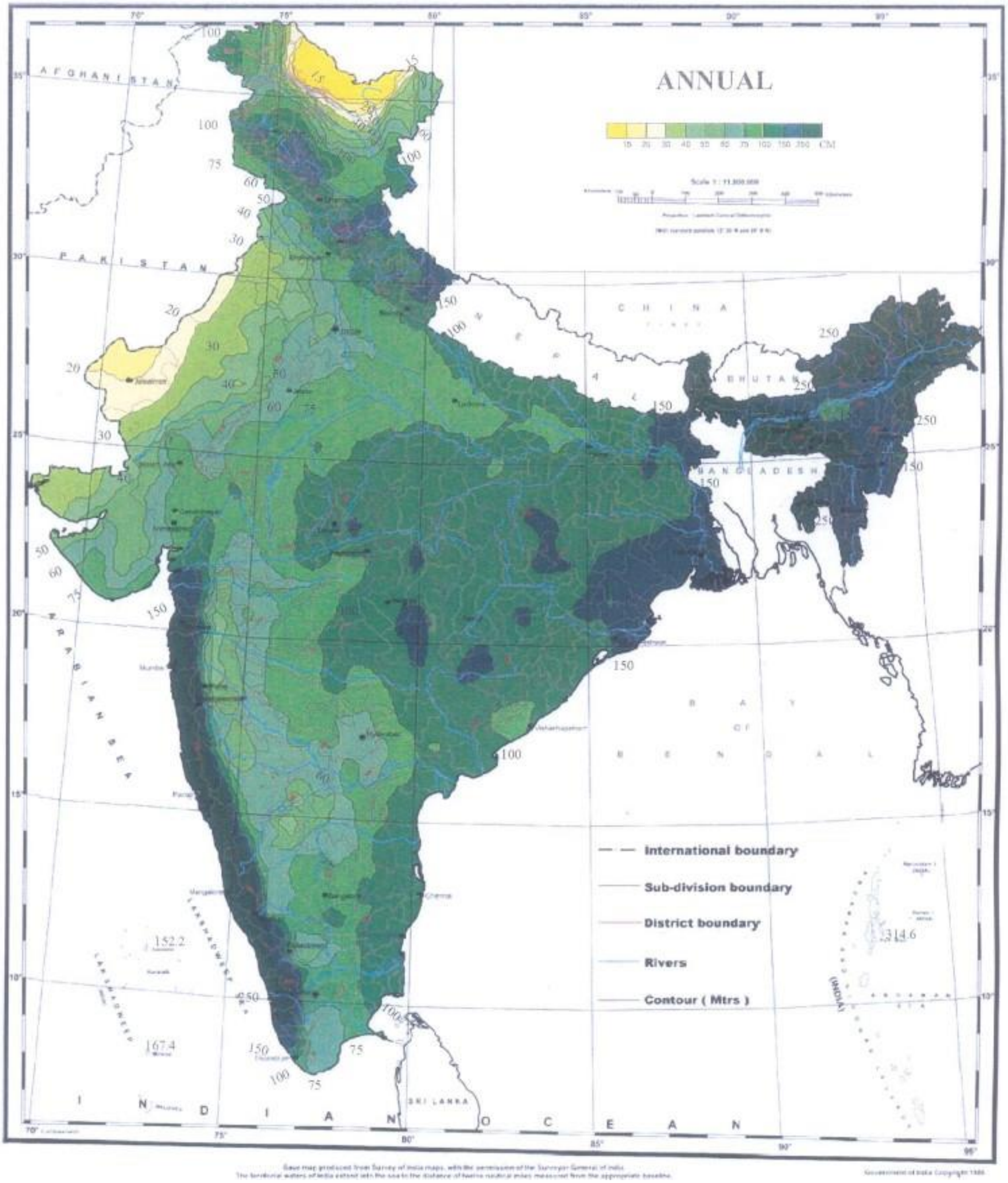
- The storms of Arabian sea originate between 12°N and 17°N latitudes in October and between 8° N and 13° N latitudes in November.
- Generally they move away from the coast in a north-westerly direction. But about 25% of them later recurve northeast and strike the **Maharashtra or Gujarat coast.**
- In north-west India the western disturbances produce clouding and light rainfall in the otherwise fine weather.
- The precipitation is in the form of snow in higher reaches of Jammu and Kashmir, Himachal Pradesh and in Kumaon Hills.

Precipitation during Retreating Monsoon Season

- The humidity and cloud cover are much reduced with the retreat of the south-west monsoons and most parts of the country remain without much rainfall.
- October-November is the **main rainy season in Tamil Nadu** and adjoining areas of **Andhra Pradesh** to the south of the Krishna delta as well as a secondary rainy period for Kerala.

RAINFALL (cm)

Map No. 49



- The retreating monsoons absorb moisture while passing over the **Bay of Bengal** and cause this rainfall.

Annual Rainfall [South West Monsoons + Retreating Monsoons]

Areas of very high rainfall

- Areas receiving an annual rainfall of 200 cm and above.
- These include western side of Western Ghats [Thiruvananthapuram in the south to Mumbai in the north].
- The average annual rainfall in this belt is 200-400 cm.
- Assam, Nagaland, Meghalaya, Mizoram, Arunachal Pradesh, Sikkim, parts of Manipur, Tripura and north-eastern tip of West Bengal also receive 200 cm or more, with isolated pockets receiving over 400 cm.

Meghalaya (the abode of clouds) is the wettest part of the country with Mawsynram and Cherrapunji getting 1,221 and 1,102 cm of annual rainfall respectively.

Areas of high rainfall

- 100-200 cm annual rainfall.
- Eastern slopes of the Western Ghats, major part of the northern plain, Odisha, Madhya Pradesh, Andhra Pradesh and Tamil Nadu.

Isohyet (the line joining places of equal rainfall).

Areas of low rainfall

- 50-100 cm annual rainfall.
- Large parts of Gujarat, Maharashtra. western Madhya Pradesh, Andhra Pradesh, Karnataka, eastern Rajasthan, Punjab, Haryana and parts of Uttar Pradesh.

Areas of very low rainfall

- These are desert and semi-desert areas receiving less than 50 cm of annual rainfall.
- They include large areas of western Rajasthan, Kachchh and most of Ladakh region of Jammu and Kashmir.

Climatic Regions of India – Stamp's Classification of Climatic Regions of India: Temperate and Tropical – Koeppen's Classification of Climatic Regions of India.

Climatic Regions of India

- India has tropical monsoon climate with large regional variations in terms of rainfall and temperature.
- While classifying Indian climatic regions, most geographers have given more importance to **rainfall** than to temperature as variations in rainfall are much more marked than those of temperature.

Here we will see two classifications - Stamp's and Koeppen's. For GS this is more than enough.

Stamp's Classification of Climatic Regions of India

- Stamp used **18°C isotherm** of mean monthly temperature for January to divide the country into two broad climatic regions, viz., **temperate or continental zone** in the north and **tropical zone** in the south.

- This line runs roughly across the root of the peninsula, more or less along or parallel to the Tropic of Cancer.
- The two major climatic regions are further divided into eleven regions depending upon the amount of rainfall and temperature.

Temperate or Continental India

1. The Himalayan region (heavy rainfall)
2. The north-western region (moderate rainfall)
3. The arid low land
4. The region of moderate rainfall
5. The transitional zone

Tropical India

1. Region of very heavy rainfall
2. Region of heavy rainfall
3. Region of moderate rainfall
4. The Konkan Coast
5. The Malabar Coast
6. Tamil Nadu

Temperate or Continental India		
Region	**Avg Temperature**	**Annual Rainfall**
Himalayan Region	Sumer = 4°-7°C Winter = 13°-18°C	East = Over 200 cm West = much less
North-western Region Northern parts of Punjab and southern parts of Jammu and Kashmir	Summer = 16°C Winter = 24°C	Below 200 cm
Arid Lowland Thar desert of Rajasthan, south western part of Haryana and Kachchh of Gujarat	Winter = 16° to 24°C Summer = 48°C	Below 40 cm
Region of moderate rainfall Punjab, Haryana, western Uttar Pradesh, Union Territory of Delhi, north-west Plateau area of Madhya Pradesh and eastern Rajasthan	Winter = 15°-18°C Summer = 33°-35°C	40 - 80 cm
Transitional Zone Eastern Uttar Pradesh and Bihar	Winter = 15°-19°C Summer = 30° - 35°C	100 -150 cm
Tropical India		
Region of very heavy rainfall Meghalaya, Assam, Tripura, Mizoram and Nagaland	Winter = 18°C in Summer = 32°-35°C	Over 200
Region of heavy rainfall Chhattisgarh, Jharkhand, Gangetic West Bengal, Odisha and coastal Andhra Pradesh	Winter = 18°-24°C Summer = 29°-35°C	100 - 200 cm
Region of moderate rainfall between Western and Eastern Ghats	Winter = 18°-24°C Summer = 32°C in	50 -100 cm
Konkan Coast Mumbai in the north to Goa in the south	Annual = 24°-27°C.	Over 200 cm
Malabar Coast Goa to Kanniyakumari	Annual = 27°C	Over 250 cm
Tamil Nadu Tamil Nadu and adjoining areas of Andhra Pradesh	Annual = 24°C	100 to 150 cm **(Retreating monsoon)**

Koeppen's Classification of Climatic Regions of India

- Koeppen's Classification of Climatic Regions of India is an empirical classification based on mean annual and mean monthly temperature and precipitation data.

- Koeppen identified a close relationship between the distribution of vegetation and climate.
- He selected certain values of temperature and precipitation and related them to the distribution of vegetation and used these values for classifying the climates.
- Koeppen recognized five major climatic groups, four of them are based on temperature and one on precipitation.
- The capital letters:

1. **A, C, D and E delineate humid climates and**
2. **B dry climates.**

[Don't have to remember all these alphabets. Only remember the climatic regions and their characteristics. That's enough

Alphabet codes will help you to remember the concept in the long run. But if you found them hard, just ignore them]

- The climatic groups are subdivided into types, designated by small letters, based on seasonality of precipitation and temperature characteristics.
- The seasons of dryness are indicated by the small letters : f, m, w and s, where

a) **f - no dry season,**
b) **m - monsoon climate,**
c) **w - winter dry season and**
d) **s - summer dry season.**

- The above mentioned major climatic types are further subdivided depending upon the seasonal distribution of rainfall or degree of dryness or cold.

a: hot summer, average temperature of the warmest month over 22°C

c: cool summer, average temperature of the warmest month under 22°C

f: no dry season

w: dry season in winter

s: dry season in summer

g: Ganges type of annual march of temperature; hottest month comes before the solstice and the summer rainy season.

h: average annual temperature under 18°C

m (monsoon): short dry season.

- The capital letters S and W are employed to designate the two subdivisions of dry climate:

1. **semi-arid or Steppe (S) and**
2. **arid or desert (W).**

- Capital letters T and F are similarly used to designate the two subdivisions of polar climate

1. **tundra (T) and**
2. **icecap (F).**

Table 12.2 : Climatic Types According to Koeppen

Group	*Type*	*Letter Code*	*Characteristics*
A-Tropical Humid Climate	Tropical wet	Af	No dry season
	Tropical monsoon	Am	Monsoonal, short dry season
	Tropical wet and dry	Aw	Winter dry season
B-Dry Climate	Subtropical steppe	BSh	Low-latitude semi arid or dry
	Subtropical desert	BWh	Low-latitude arid or dry
	Mid-latitude steppe	BSk	Mid-latitude semi arid or dry
	Mid-latitude desert	BWk	Mid-latitude arid or dry
C-Warm temperate (Mid-latitude) Climates	Humid subtropical	Cfa	No dry season, warm summer
	Mediterranean	Cs	Dry hot summer
	Marine west coast	Cfb	No dry season, warm and cool summer
D-Cold Snow-forest Climates	Humid continental	Df	No dry season, severe winter
	Subarctic	Dw	Winter dry and very severe
E-Cold Climates	Tundra	ET	No true summer
	Polar ice cap	EF	Perennial ice
H-Highland	Highland	H	Highland with snow cover

- Koeppen divided India into nine climatic regions making use of the above scheme.

Koeppen's Scheme – Climatic Regions of India		
Climate type	**Region**	**Annual rainfall**
Amw (Monsoon type with short dry winter season)	Western coastal region, south of Mumbai	over 300 cm
As (Monsoon type with dry season in high sun period)	Coromandel coast = Coastal Tamil Nadu and adjoining areas of Andhra Pradesh	75 - 100 cm [wet winters, dry summers]
Aw (Tropical Savanah type)	Most parts of the peninsular plateau barring Coromandel and Malabar coastal strips	75 cm
BShw (Semi-arid Steppe type)	Some rain shadow areas of Western Ghats, large part of Rajasthan and contiguous areas of Haryana and Gujarat	12 to 25 cm
BWhw (Hot desert type)	Most of western Rajasthan	less than 12 cm
Cwg (Monsoon type with dry winters)	Most parts of the Ganga Plain, eastern Rajasthan, Assam and in Malwa Plateau	100 - 200 cm
Dfc (Cold, Humid	Sikkim, Arunachal Pradesh and parts of Assam	~200 cm

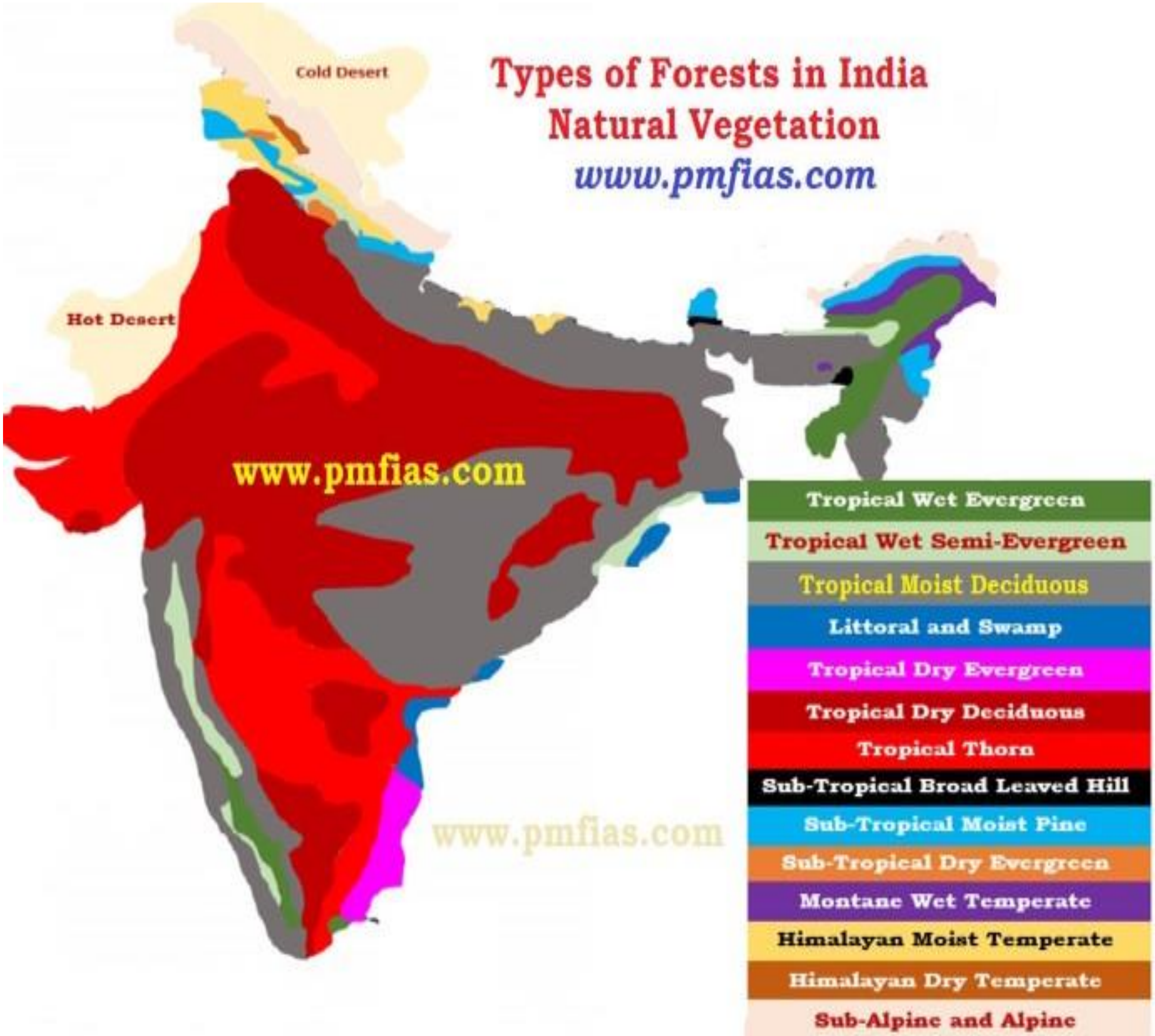
winters type with shorter summer)		
Et (Tundra Type)	Mountain areas of Uttarakhand The average temperature varies from 0 to 10°C	Rainfall varies from year to year.
E (Polar Type)	Higher areas of Jammu & Kashmir and Himachal Pradesh in which the temperature of the warmest month varies from 0° to 10°C	Precipitation occurs in the form of snow
Source: Indian Geography KULLAR		

Natural Vegetation of India

- **Climate, soil and topography** are the major factors that influence Natural Vegetation of a place.
- The main climatic factors are **rainfall and temperature**. The amount of annual rainfall has a great bearing on the type of vegetation.

Annual Rainfall	Type of Vegetation
200 cm or more	**Evergreen Rain Forests**
100 to 200 cm	**Monsoon Deciduous Forests**
50 to 100 cm	**Drier Deciduous or Tropical Savanna**
25 to 50 cm	**Dry Thorny Scrub (Semi-arid)**
Below 25 cm	**Desert (Arid)**

- Temperature is the major factor in Himalayas and other hilly regions with an elevation of more than 900 metres.
- As the temperature falls with altitude in the Himalayan region the vegetal cover changes with altitude from **tropical to sub-tropical, temperate and finally alpine.**
- Soil is an equally determining factor in few regions. **Mangrove forests, swamp forests** are some of the examples where soil is the major factor.
- Topography is responsible for certain minor types e.g. **alpine flora, tidal forests, etc..**



Classification Of Natural Vegetation of India

- Classification of Natural Vegetation of India is primarily based on spatial and annual variations in rainfall. Temperature, soil and topography are also considered.
- India's vegetation can be divided into 5 main types and 16 sub-types as given below.

A. Moist Tropical Forests

1. Tropical Wet Evergreen
2. Tropical Semi-Evergreen
3. Tropical Moist Deciduous
4. Littoral and Swamp

B. Dry Tropical Forest

1. Tropical Dry Evergreen
2. Tropical Dry Deciduous
3. Tropical Thorn

C. Montane Sub-tropical Forests

1. Sub-tropical broad leaved hill
2. Sub-tropical moist hill (pine)
3. Sub-tropical dry evergreen

D. Montane Temperate Forests

1. Montane Wet Temperate
2. Himalayan Moist Temperate
3. Himalayan Dry Temperate

E. Alpine Forests

1. Sub-Alpine
2. Moist Alpine scrub

3. Dry Alpine scrub

Forest Type in India	% of Total Area
Tropical Moist Deciduous	**37**
Tropical Dry Deciduous	**28**
Tropical Wet Evergreen	**8**
Sub-Tropical Moist Hill	**6**
Tropical Semi-Evergreen	**4**
Rest below 4 %	

Moist Tropical Forests

Tropical Wet Evergreen Forests or Rain Forests

Climatic Conditions

1. Annual rainfall exceeds 250 cm
2. The annual temperature is about 25°-27°C
3. The average annual humidity exceeds 77 per cent and
4. The dry season is distinctly short.

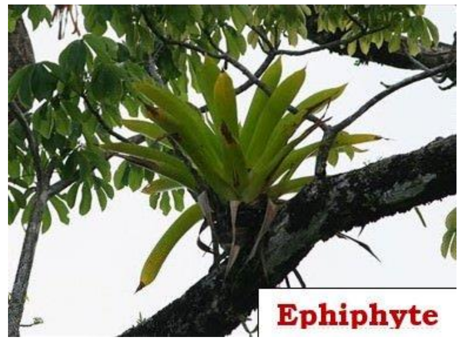
Characteristics

- Evergreen: Due to high heat and high humidity, the trees of these forests do not shed their leaves together.
- **Mesosphytic**: **Plants adopted to neither too dry nor too wet type climate.**

What are mesophytes?

Unlike **hydrophytic plants**, such as water lily or pondweed, that grow in saturated soil or water, or **xerophytic plants**, such as cactus, that grow in extremely dry soil, mesophytes are ordinary plants that **exist between the two extremes.**
Mesophytic environments are marked by average to hot temperatures and soil that is **neither too dry nor too wet.**

- Lofty: The trees often reach 45 – 60 metres in height.
- Thick Canopy: From the air, the tropical rain forest appears like a thick canopy of foliage, broken only where it is crossed by large rivers or cleared for cultivation.
- All plants struggle upwards (most **ephiphytes**) for sunlight resulting in a peculiar layer arrangement. The entire morphology looks like a green carpet when viewed from above.


Ephiphyte

- Less undergrowth: The sun light cannot reach the ground due to thick canopy. The undergrowth is formed mainly of bamboos, ferns, climbers, orchids, etc.

Distribution

1. Western side of the Western Ghats (500 to 1370 metres above sea level).
2. Some regions in the Purvanchal hills.
3. In the Andaman and Nicobar Islands.

Timber

- Hardwood: The timber of these forests is fine-grained, hard and durable.
- It has high commercial value but it is highly challenging to exploit due **to dense undergrowth, absence of pure stands and lack of transport facilities** [Read previous posts on Climatic regions to understand how lumbering industry works in Equatorial Rainforests (hardwood) and Taiga Climatic (softwood) conditions].
- The important species of these forests are **mahogany, mesua, white cedar, jamun, canes, bamboo** etc.

Tropical Semi-Evergreen Forests

- They are transitional forests between tropical wet evergreen forests and tropical deciduous forests.
- They are comparatively drier areas compared to tropical wet evergreen forests.

Climatic Conditions

- Annual rainfall is 200-250 cm
- Mean annual temperature varies from 24°C to 27°C
- The relative humidity is about 75 per cent
- The dry season is not short like in tropical evergreen forests.

Distribution

- Western coast
- Assam
- Lower slopes of the Eastern Himalayas
- Odisha and
- Andamans.

Characteristics

- The semi-evergreen forests are less dense.
- They are more **gregarious [living in flocks or colonies – more pure stands]** than the wet evergreen forests.
- These forests are characterized by many species.
- Trees usually have **buttressed trunks with abundant epiphytes.**

Buttressed Trunks

- The important species are laurel, rosewood, mesua, thorny bamboo – Western Ghats, white cedar, Indian chestnut, champa, mango, etc. – Himalayan region.

Timber

- Hardwood: Similar to that in tropical evergreen forests except that these forests are less dense with **more pure stands** (timber industry here is better than in evergreen forests).

Tropical Moist Deciduous Forests

Climatic Conditions

- Annual rainfall 100 to 200 cm.
- Mean annual temperature of about 27°C
- The average annual relative humidity of 60 to 75 per cent.
- Spring (between winter and summer) and summer are dry.

Characteristics

- The trees drop their leaves during the spring and early summer when sufficient moisture is not available.
- The general appearance is bare in extreme summers (April-May).
- Tropical moist deciduous forests present irregular top storey [25 to 60 m].
- Heavily buttressed trees and fairly complete undergrowth.
- These forests occupy a much larger area than the evergreen forests but large tracts under these forests have been cleared for cultivation.

Distribution

- Belt running along the Western Ghats surrounding the belt of evergreen forests.
- A strip along the Shiwalik range including terai and bhabar from 77° E to 88° E.
- Manipur and Mizoram.
- Hills of eastern Madhya Pradesh and Chhattisgarh.
- Chota Nagpur Plateau.
- Most of Odisha.
- Parts of West Bengal and
- Andaman and Nicobar islands.

Timber

- These provide valuable timer like **Teak.**

- The main species found in these forests are teak, sal, laurel, rosewood, amla, jamun, bamboo, etc.
- It is **comparatively easy to exploit these forests due to their high degree of gregariousness (more pure stands).**

Littoral and Swamp Forests

- They can survive and grow both in fresh as well as **brackish water** (The mixture of seawater and fresh water in estuaries is called brackish water and its salinity can range from 0.5 to 35 ppt).
- Occur in and around the deltas, estuaries and creeks prone to **tidal influences (delta or tidal forests).**
- Littoral (relating to or on the shore of the sea or a lake) forests occur at several places along the coast.
- Swamp forests are confined to the deltas of the Ganga, the Mahanadi, the Godavari, the Krishna and the Cauvery.
- Dense mangroves occur all along the coastline in sheltered estuaries, tidal creeks, backwaters, salt marshes and mudflats. It provides useful fuel wood.
- The most pronounced and the densest is the **Sunderban in the Ganga delta** where the predominant species is Sundri (Heriteera).

Timber

- It provides hard and durable timber which is used for construction, building purposes and making boats.
- The important species found in these forests are Sundri, agar, rhizophora, screw pines, canes and palms, etc.

Dry Tropical Forests

Tropical Dry Evergreen Forests

Distribution

- Along the coasts of Tamil Nadu.

Climatic Conditions

- Annual rainfall of 100 cm [mostly from the north-east monsoon winds in October – December].
- Mean annual temperature is about 28°C.
- The mean humidity is about 75 per cent.
- The growth of evergreen forests in areas of such low rainfall is a bit strange.

Characteristics

- Short statured trees, up to 12 m high, with complete canopy.
- Bamboos and grasses not conspicuous.
- The important species are jamun, tamarind, neem, etc.
- Most of the land under these forests has been cleared for agriculture or **casuarina plantations.**

Casuarina plantation

It resembles feathery conifer in general appearance.

They are rapid-growing, carefree species for sites and climates as varied as coastal sand dunes, high mountain slopes, hot humid tropics, and semi-arid regions.

They have the ability to **fix atmospheric nitrogen**. It grows 15 to 25 metres in height on an average.

Distribution

Casuarina is the most popular farm forestry in the states of Andhra Pradesh, Tamil Nadu, West Bengal, Odisha, Maharashtra, Gujarat, and Karnataka.

Benefits

Reduces damage in the event of natural

calamities.

Line planting in the coastal areas helps in controlling the wind force.

It is also used for tourism promotion in view of its ornamental appearance.

It provides top quality firewood.

The wood is suitable for paper pulp and useful raw material for the manufacture of paper for writing, printing, and wrapping.

It is got some serious medicinal values as well.

Wasteland development

The characteristics which make it a suitable species for wasteland development include adaptability to wide range of habitats, fast growth, salt tolerant, drought resistant, ability to reclaim land and stabilize sand dunes.

Intercrops such as groundnut, cucumber, watermelons, sesamum, and pulses can also be raised along with the plantation.

Tropical Dry Deciduous Forests

Climatic Conditions

- Annual rainfall is 100-150 cm.

Characteristics

- These are similar to moist deciduous forests and shed their leaves in dry season.
- The major difference is that they can grow in areas of comparatively less rainfall.
- They represent a transitional type - moist deciduous on the wetter side and thorn forests on the drier side.
- They have closed but uneven canopy.
- The forests are composed of a mixture of a few species of deciduous trees rising up to a height of 20 metres.
- Undergrowth: Enough light reaches the ground to permit the growth of grass and climbers.

Distribution

- They occur in an irregular wide strip running from the foot of the Himalayas to Kanniyakumari except in Rajasthan, Western Ghats and West Bengal.
- The important species are teak, axlewood, rosewood, common bamboo, **red sanders**, laurel, satinwood, etc.
- Large tracts of this forest have been cleared for agricultural purposes.
- These forests have suffer from over grazing, fire, etc.

Tropical Thorn Forests

Climatic Conditions

- Annual rainfall less than 75 cm.
- Humidity is less than 50 per cent.
- Mean temperature is 25°-30°C.

Characteristics

- The trees are low (6 to 10 metres maximum) and widely scattered.
- Acacias and Euphorbias are very prominent.
- The Indian wild date is common. Some grasses also grow in the rainy season.

Distribution

- Rajasthan, south-western Punjab, western Haryana, Kachchh and neighbouring parts of Saurashtra.
- Here they degenerate into desert type in the Thar desert.
- Such forests also grow on the leeside of the Western Ghats covering large areas of Maharashtra, Karnataka, Telangana, Andhra Pradesh and Tamil Nadu.
- The important species are neem, babul, cactii, etc.

Montane Sub-Tropical Forests

Sub-tropical Broad-leaved Hill Forests

Climatic conditions

- Mean annual rainfall is 75 cm to 125 cm.
- Average annual temperature is 18°-21°C.
- Humidity is 80 per cent.

Distribution

- Eastern Himalayas to the east of 88°E longitude at altitudes varying from 1000 to 2000 m.

Characteristics

- Forests of evergreen species.
- Commonly found species are evergreen oaks, chestnuts, ash, beech, sals and pines.
- Climbers and epiphytes [a plant that grows non-parasitically on a tree or other plant] are common.
- These forests are not so distinct in the southern parts of the country. They occur only in the Nilgiri and Palni hills at 1070-1525 metres above sea level.
- It is a "stunted rain-forest" and is not so luxuriant as the true tropical evergreen.
- The higher parts of the Western Ghats such as Mahabaleshwar, the summits of the Satpura and the Maikal Range, highlands of Bastar and Mt. Abu in the Aravali Range carry sub-types of these forests.

Sub-tropical Moist Pine Forests

Distribution

- Western Himalayas between 73°E and 88°E longitudes at elevations between 1000 to 2000 metres above sea level.
- Some hilly regions of Arunachal Pradesh, Manipur, Naga Hills and Khasi Hills.

Timber

- **Chir or Chil** is the most dominant tree which forms pure stands.
- It provides **valuable timber** for furniture, boxes and buildings.
- It is also used for producing resin and turpentine.

Sub-tropical Dry Evergreen Forests

Distribution

- Found in the Bhabar, the Shiwaliks and the western Himalayas up to about 1000 metres above sea level.

Climatic Conditions

- Annual rainfall is 50-100 cm (15 to 25 cm in December-March).
- The summers are sufficiently hot and winters are very cold.

Characteristics

- Low scrub forest with small evergreen stunted trees and shrubs.
- Olive, acacia modesta and pistacia are the most predominant species.

Montane Temperate Forests

Montane Wet Temperate Forests

Climatic Conditions

- Grows at a height of 1800 to 3000 m above sea level
- Mean annual rainfall is 150 cm to 300 cm
- Mean annual temperature is about 11°C to 14°C and the
- Average relative humidity is over 80 per cent.

Distribution

- Higher hills of Tamil Nadu and Kerala, in the Eastern Himalayan region.

Characteristics

- These are closed evergreen forests. Trunks have large girth.
- Branches are clothed with mosses, ferns and other epiphytes.
- The trees rarely achieve a height of more than 6 metres.
- Deodar, Chilauni, Indian chestnut, birch, plum, machilus, cinnamomum, litsea, magnolia, blue pine, oak, hemlock, etc. are important species.

Himalayan Moist Temperate Forests

Climatic Conditions

- Annual rainfall varies from 150 cm to 250 cm

Distribution

- Occurs in the temperate zone of the Himalayas between 1500 and 3300 metres.
- Cover the entire length of this mountain range in Kashmir, Himachal Pradesh, Uttarakhand, Darjeeling and Sikkim.

Characteristics

- Mainly composed of **coniferous species.**
- Species occur in mostly pure strands.
- Trees are 30 to 50 m high.
- Pines, cedars, silver firs, spruce, etc. are most important trees.
- They form high but fairly open forest with shrubby undergrowth including oaks, rhododendrons and some bamboos.

Timber

- It provides fine wood which is of much use for construction, timber and railway sleepers.

Himalayan Dry Temperate Forests

Climatic Conditions

- Precipitation is below 100 cm and is mostly in the form of snow.

Characteristics

- Coniferous forests with xerophytic shrubs in which deodar, oak, ash, olive, etc are the main trees.

Distribution

- Such forests are found in the inner dry ranges of the Himalayas where south-west monsoon is very feeble.
- Such areas are in Ladakh, Lahul, Chamba, Kinnaur, Garhwal and Sikkim.

Alpine Forests

- Altitudes ranging between 2,900 to 3,500.
- These forests can be divided into: (1) sub-alpine; (2) moist alpine scrub and (3) dry alpine scrub.
- The sub-alpine forests occur lower alpine scrub and grasslands.
- It is a mixture of coniferous and broad-leaved trees in which the coniferous trees attain a height of about 30 m while the broad leaved trees reach only 10 m.
- Fir, spruce, rhododendron, etc. are important species.
- The moist alpine scrub is a low evergreen dense growth of rhododendron, birch etc. which occurs from 3,000 metres and extends upto snowline.
- The dry alpine scrub is the uppermost limit of scrub xerophytic, dwarf shrubs, over 3,500 metres above sea level and found in dry zone. Juniper, honeysuckle, artemesia etc. are important species.

Soil – Soil Types: Sandy-Clayey-Loamy. Soil Profile – Soil Horizon: O horizon, A Horizon, E horizon, B Horizon, C Horizon or Parent rock, R Horizon or Bedrock.

Soil

- Soil is the thin top layer on the earth's crust comprising rock particles mixed with organic matter.
- **Pedology** is the study of soils in their natural environment. **Pedogenesis** is the natural process of soil formation that includes a variety of processes such as weathering, leaching, calcification etc..
- The Soil formation is mainly related to the parent rock material, surface relief, climate and natural vegetation.
- The soil is formed by the breaking down of rocks by the action of wind, water and climate. This process is called **weathering.**

Soil Types – Sandy-Clayey-Loamy

- The soil is classified on the basis of the proportion of particles of various sizes.

(a) If soil contains greater proportion of big particles it is called **sandy soil.**

(b) If the proportion of fine particles is relatively higher, then it is called **clayey soil.**

(c) If the amount of large and fine particles is about the same, then the soil is called **loamy.**

1. Water can drain quickly through the spaces between the sand particles. So, sandy soils tend to be light, well aerated and dry.
2. Clay particles, being much smaller, pack tightly together, leaving little space for air. Unlike sandy soil, water can be held in the tiny gaps between the particles of clay. So clay soils have little air. But they are heavy as they hold more water than the sandy soils.
3. The best topsoil for growing plants is loam. Loamy soil is a mixture of sand, clay and another type of soil particle known as silt. Silt occurs as a deposit in river beds. The size of the silt particles is between those of sand and clay. The loamy soil also has humus in it. It has the right water holding capacity for the growth of plants.

- **Clayey and loamy soils are both suitable for growing cereals like wheat, and gram. Such soils are good at retaining water.**
- **For paddy, soils rich in clay and organic matter and having a good capacity to retain water are ideal.**
- **For lentils (masoor) and other pulses, loamy soils, which drain water easily, are required.**
- **For cotton, sandy loam or loam, which drain water easily and can hold plenty of air, are more suitable.**

Soil Profile – Soil Horizon

- A vertical section through different layers of the soil is called the soil profile.
- Each layer differs in feel (texture), colour, depth and chemical composition. These layers are referred to as horizons.
- A soil horizon is a layer generally parallel to the soil surface, whose physical characteristics differ from the layers above and beneath.
- Horizons are defined in most cases by obvious physical features, chiefly colour and texture.
- The uppermost horizon is generally dark in colour as it is rich in humus and minerals. The humus makes the soil fertile and provides nutrients to growing plants.
- This layer is generally soft, porous and can retain more water. It is called the topsoil or the A-horizon.
- The next layer has a lesser amount of humus but more of minerals. This layer is generally harder and more compact and is called the B-horizon or the middle layer.
- The third layer is the C-horizon, which is made up of small lumps of rocks with cracks.

O Horizon

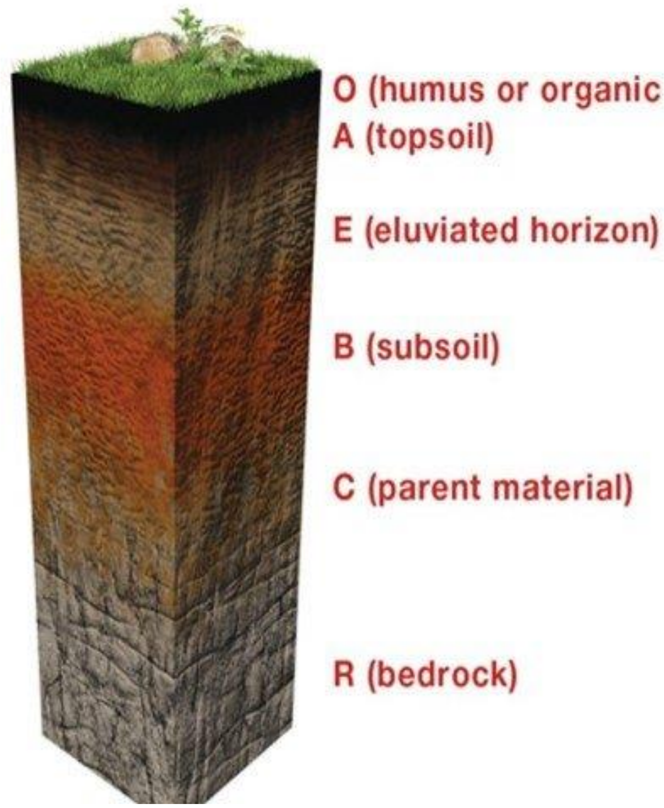
- Layers dominated by organic material.
- Some O layers consist of undecomposed or partially decomposed litter (such as leaves, needles, twigs, moss, and lichens).
- They may be on top of either mineral or organic soils.

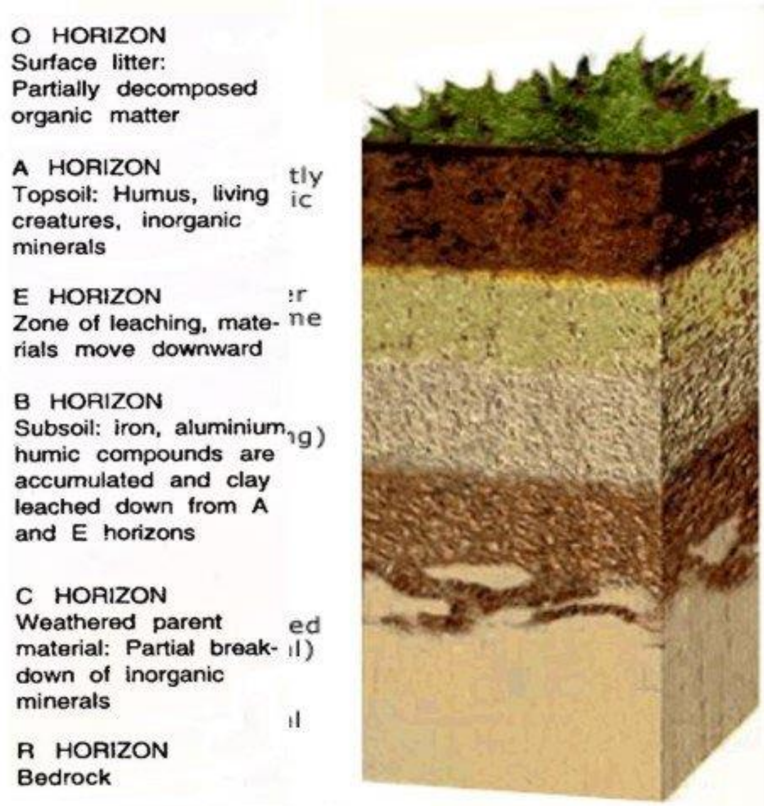
A Horizon or Surface soil

- It is the part of top soil.
- In this layer, organic matter is mixed with mineral matter.
- It is the layer of mineral soil with the most organic matter accumulation and soil life.
- This layer is depleted of (eluviated of) iron, clay, aluminum, organic compounds, and other soluble constituents.
- When depletion is pronounced, a lighter colored "E" subsurface soil horizon is apparent at the base of the "A" horizon.

E horizon

- "E" stands for eluviated layer.
- It is the horizon that has been significantly leached of clay, iron, and aluminum oxides, which leaves a concentration of resistant minerals, such as quartz, in the sand and silt sizes.
- These are present only in older, well-developed soils, and generally occur between the A and B horizons.





B Horizon or Subsoil

- It is subsurface layer reflecting chemical or physical alteration of parent material.
- This layer accumulates all the leached minerals from A and E horizon.
- Thus iron, clay, aluminum and organic compounds accumulate in this horizon [illuviation (opposite of eluviation)].

C Horizon or Parent rock

- Weathered parent material accumulates in this layer, i.e. the parent material in sedimentary deposits.
- It is a layer of large unbroken rocks.
- This layer may accumulate the more soluble compounds (inorganic material).

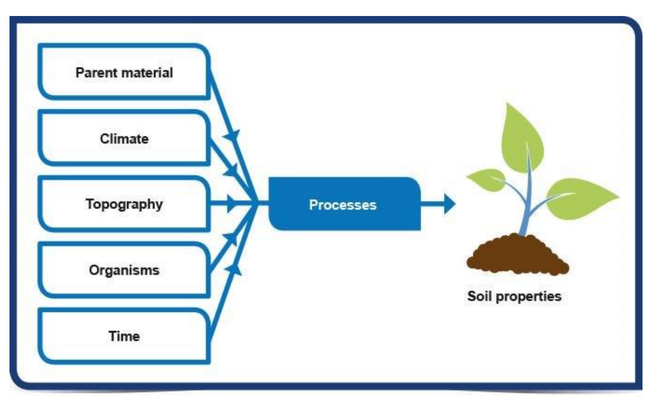
R Horizon or Bedrock

- This layer denotes the layer of partially weathered bedrock at the base of the soil profile.
- Unlike the above layers, R horizons largely comprise continuous masses of hard rock.
- Soils formed in situ will exhibit strong similarities to this bedrock layer.
- These areas of bedrock are under 50 feet of the other profiles.

Soil formation in Indian Conditions – Factors that influence soil formation: Parent Material – Gondwana rocks & Deccan basalts, Relief, Climate & Natural Vegetation.

Factors that influence soil formation in Indian Conditions

- **Parent Material**
- **Relief**
- **Climate**
- **Natural Vegetation**



Parent Material

- The rocks from which soils are formed are called parent materials.
- In most of the cases, the parent material determines the **colouration, mineral composition and texture of the soil.**
- In some cases, the soil formed may or may not have the same physical properties of the parent rock.
- Climatic factors induce chemical changes which also affect physical properties of the soil.
- The surface rocks are exposed to the process of weathering. In this process, the rocks are converted into fine grains and provide a base for the soil formation.
- In Indian Conditions, parent material is generally categorized into:

1. ***Ancient crystalline and metamorphic rocks***
2. ***Cuddapah and Vindhyan rocks***
3. ***Gondwana rocks***
4. ***Deccan basalts***
5. ***Tertiary and Mesozoic sedimentary rocks of extra peninsular India {Rock System}***

Ancient crystalline and metamorphic rocks

- They are the **Oldest rocks** [(pre-Cambrian era)(formed due to solidification of molten magma about 4billion years ago)].
- They form the **'Basement Complex'** of peninsular India.
- They are basically **granites, gniesses and schists**.
- These rocks are rich in ferromagnetic materials and give rise to **red soils** on weathering.
- The red colour of these soils is due to the presence of **iron oxide.**

Cuddapah and Vindhyan rocks

- They are ancient sedimentary rocks (4000 m thick).
- On weathering they give **calcareous** [containing calcium carbonate; chalky] and **argillaceous** [consisting of or containing clay] soils.
- The soil is mostly devoid of metalliferous minerals.

Gondwana rocks

- These rocks are also sedimentary in nature and they are much younger.
- On weathering they give rise to comparatively **less mature soils.**
- The soil is more or less of uniform character but of **low fertility.**

Deccan basalts

- Volcanic outburst over a vast area of the Peninsular India many hundred million years ago gave rise to Deccan Traps.
- Basaltic lava flowed out of fissures covering a vast area of about ten lakh sq km.
- Basalts are rich in **titanium, magnetite, aluminium and magnesium.**
- Consequently the weathering of these rocks has given rise to soils of **darker colour.**
- The is fertile with **high moisture holding capacity** and is popularly known as **'regur' or black cotton soil.**

Tertiary and Mesozoic sedimentary rocks

- Rocks of extra peninsular (plains and Himalayas) India have given rise to soils with **high porosity.**
- These soils are generally immature recent and sub recent rocks, result in **alluvial soils on weathering.**
- Alluvial fertile soils consist of fine silts and clay. These soils have **little relation with the original rocks.**
- On the other hand, the soils of peninsular plateau are generally coarse-grained and are closely related to the parent rocks. The peninsular soils are generally less fertile.

Relief

- The relief is the most important factor for soil formation in places with steep slopes like the hilly regions, edges of plateaus etc.

- Soil erosion on barren slopes is rampant and it hinders soil formation. Example: **Chambal ravines**, higher reaches of Himalayas where there is minimal or no forest cover (most on the steep southern slopes) etc.
- The areas of low relief or gentle slope generally experience deposition and have deep soils. Example: Indo-Gangetic plain.
- The exceptions in the plateau are river basins where the soil layers are sufficiently deep.

Climate

- Temperature and rainfall are the most important factors in soil formation.
- They determine the effectiveness of weathering of the parent material, the quantity of water seeping through the soil and the type of micro-organisms present therein.
- Two different parent materials may develop the same soil in the same type of climate. Similarly, the same parent material may produce two different types of soils in two different types of climates.
- **The crystalline granites produce laterite soil in relatively moist parts of the monsoonal region and non-laterite soil in drier areas.**
- **Hot summer and low rainfall develops black soil as is found in some parts of Tamil Nadu irrespective of the parent rock.**
- **In Rajasthan, both granite and sandstone give birth to sandy soil under arid climate.**
- In arid and semi-arid regions, evaporation always exceeds precipitation. There is little vegetation and the soils badly lack humus content. Hence the soils are invariably of **light colour.**
- In Rajasthan and the adjoining arid and semi-arid regions, excess of evaporation makes soils lime accumulating. Hence the soil is pedocal in nature [Pedocal is a subdivision of the zonal soil order. It is a class of soil which forms in semiarid and arid regions. It is **rich in calcium carbonate** and has **low soil organic matter**].
- In cold climates of the Himalayan region, the process of vegetation **decay is very slow** and the soils are **acidic in nature.**

In areas of heavy rainfall and high temperature, the soils are red or lateritic. Why?

- Torrential rainfall during the rainy season washes the upper soil and **leaches** the materials into deeper horizon.
- During the dry summer season the evaporation exceeds precipitation and through capillary action **iron and aluminium oxides** are transported to the surface making the soil red.
- In areas of alternate wet and dry climate, the leached material which goes deep down in the horizon is brought up and the blazing sun bakes the top soil so hard that it resembles a brick. Therefore, this soil is called **lateritic which literally means brick.**

Natural Vegetation

- Natural vegetation reflects the combined effects of relief and climate.
- The formation and development of soil is very much influenced by the growth of vegetation.
- The decayed leaf material adds much needed humus to soil thereby increasing its fertility.
- The densely forested areas contain some of the best soils in India. There is a close relationship between the vegetation types and soil types in India.

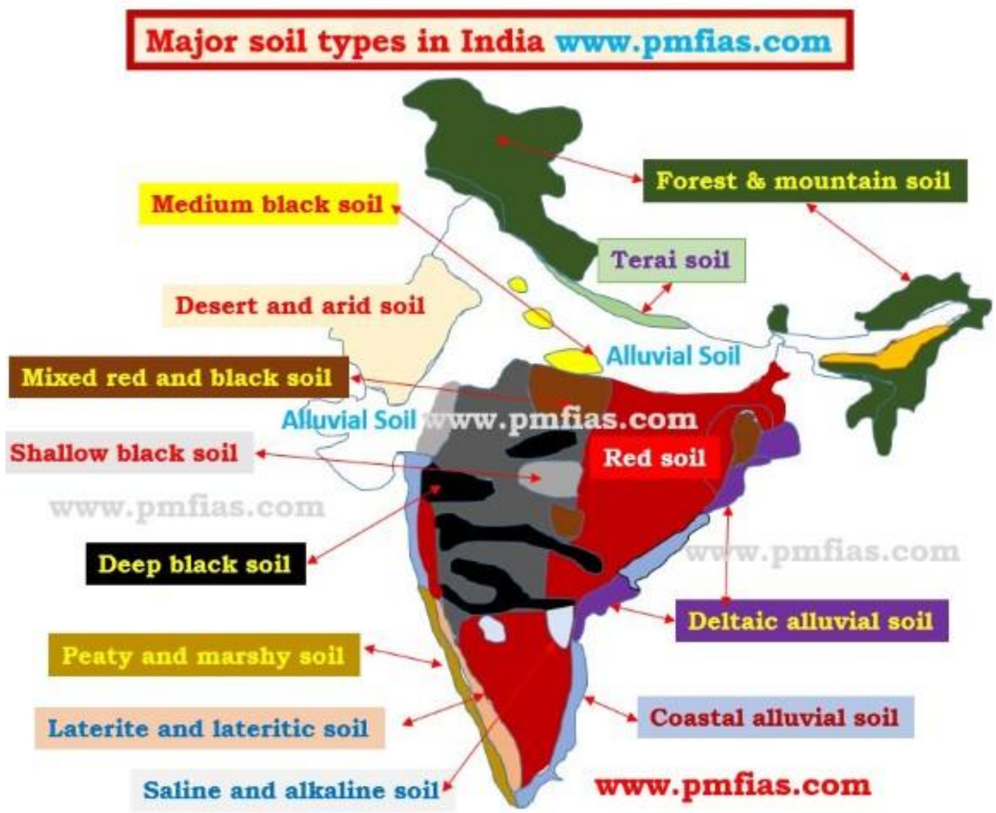
Major Soil Groups of India – Alluvial Soils – Black Soils – Characteristics, Chemical properties, Distribution, Crops, Geological divisions: Bhabar, Terai, Bhangar, Khadar.

Major Soil Groups of India

- Geologically, Indian soils can broadly be divided into soils of peninsular India and soils of extra-peninsular India.

- The soils of Peninsular India are formed by the decomposition of rocks in situ, i.e. directly from the underlying rocks.
- Soils of Peninsular India are transported and re-deposited to a limited extent and are known as **sedentary soils.**
- The soils of the Extra-Peninsula are formed due to the depositional work of rivers and wind. They are very deep. They are often referred to as **transported or azonal soils.**
- Major groups:

(1) Alluvial soils,
(2) Black soils,
(3) Red soils,
(4) Laterite and Lateritic soils,
(5) Forest and Mountain soils,
(6) Arid and Desert soils,
(7) Saline and Alkaline soils and
(8) Peaty and Marshy soils.



Alluvial Soils

- Alluvial soils are formed mainly due to silt deposited by Indo-Gangetic-Brahmaputra rivers. In coastal regions some alluvial deposits are formed due to wave action.
- Rocks of the Himalayas form the parent material. Thus the parent material of these soils is of transported origin.
- They are the largest soil group covering about 15 lakh sq km or about **45.6 per cent** of the total area.
- They support more than 40% of the India's population by providing the most productive agricultural lands.

Characteristics of Alluvial Soils

- They are **immature and have weak profiles** due to their recent origin.
- Most of the soil is **loamy.** Sandy and clayey soils are not uncommon.
- Pebbly and gravelly soils are rare. Kankar (calcareous concretions) beds are present in some regions along the river terraces.
- The soil is **porous** because of its loamy (equal proportion of sand and clay) nature.
- Porosity and texture provide good drainage and other conditions favorable for agriculture.
- These soils are constantly replenished by the recurrent floods.

Chemical properties of Alluvial Soils

- The proportion of nitrogen is generally low.
- The proportion of Potash, phosphoric acid and alkalies are adequate
- The proportion of Iron oxide and lime vary within a wide range.

Distribution of Alluvial Soils in India

- They occur all along the Indo-Gangetic-Brahmaputra plains except in few places where the top layer is covered by desert sand.
- They also occur in deltas of the Mahanadi, the Godavari, the Krishna and the Cauvery, where they are called **deltaic alluvium** (coastal alluvium)
- Some alluvial soils are found in the Narmada, Tapi valleys and Northern parts of Gujarat.

Crops in Alluvial Soils

- They are mostly flat and regular soils and are best suited for agriculture.
- They are best suited to irrigation and respond well to canal and well/tube-well irrigation.
- They yield splendid crops of rice, wheat, sugarcane, tobacco, cotton, jute, maize, oilseeds, vegetables and fruits.

Geological divisions of alluvial soils

- Geologically, the alluvium of the Great plain of India is divided into newer or younger khadar and older bhangar soils.

Bhabar

- The bhabar belt is about 8-16 km wide running along the Shiwalik foothills. It is a porous, northern most stretch of Indo-Gangetic plain.
- Rivers descending from the Himalayas deposit their load along the foothills in the form of **alluvial fans.** These alluvial fans (often pebbly soils) have merged together to build up the bhabar belt.
- The porosity of bhabar is the most unique feature. The porosity is due to deposition of huge number of pebbles and rock debris across the alluvial fans.
- The streams disappear once they reach the bhabar region because of this porosity. Therefore, the area is marked by **dry river courses** except in the rainy season.
- **The area is not suitable for agriculture and only big trees with large roots thrive in this belt.**

Terai

- Terai is an **ill-drained, damp (marshy) and thickly forested narrow tract** (15-30 km wide) to the south of Bhabar running parallel to it.
- The underground streams of the Bhabar belt re-emerge in this belt. It is a swampy lowland with silty soils.
- The terai soils are **rich in nitrogen** and organic matter but are **deficient in phosphate.**
- These soils are generally covered by tall grasses and forests but are suitable for a number of crops such as wheat, rice, sugarcane, jute etc..
- **This thickly forested region provides shelter to a variety of wild life.**

Bhangar

- The Bhangar is the older alluvium along the river beds forming terraces higher than the flood plain (about 30 metres above the flood level).
- It is of a more clayey composition and is generally dark colored.
- A few metres below the terrace of the bhangar are beds of lime nodules known as **kankar.**

Khadar

- The Khadar is composed of newer alluvium and forms the flood plains along the river banks.
- The banks are flooded almost every year and a new layer of alluvium is deposited with every flood. This makes them the most fertile soils of Ganges.
- They are sandy clays and loams, more dry and leached, less calcareous and carbonaceous (less kankary). A new layer

of alluvium is deposited by river flood almost every year.

Black Soils

- The parent material for most of the black soil are the volcanic rocks that were formed in the Deccan Plateau (Deccan and the Rajmahal trap).
- In Tamil Nadu, gneisses and schists form the parent material. The former are sufficiently deep while the later are generally shallow.
- These are the region of high temperature and low rainfall. It is, therefore, a soil group typical to the dry and hot regions of the Peninsula.

Characteristics of Black Soils

- A typical black soil is highly argillaceous [Geology (of rocks or sediment) consisting of or containing clay] with a large clay factor, 62 per cent or more.
- In general, black soils of uplands are of low fertility while those in the valleys are very fertile.
- The black soil is highly retentive of moisture. It swells greatly on accumulating moisture. Strenuous effort is required to work on such soil in rainy season as it gets very sticky.
- In summer, the moisture evaporates, the soil shrinks and is seamed with broad and deep cracks. The lower layers can still retain moisture. The cracks permits oxygenation of the soil to sufficient depths and the soil has extraordinary fertility.

Colour of Black Soils

- The black colour is due to the presence of a small proportion of **titaniferous magnetite or iron and black constituents of the parent rock.**
- In Tamil Nadu and parts of Andhra Pradesh, the black colour is derived from crystalline schists and basic gneisses.
- Various tints of the black colour such as deep black, medium black, shallow black , a mixture of red and black may be found in this group of soils.

Chemical Composition of Black Soils

- 10 per cent of alumina,
- 9-10 per cent of iron oxide,
- 6-8 per cent of lime and magnesium carbonates,
- Potash is variable (less than 0.5 per cent) and
- **phosphates, nitrogen and humus are low.**

Distribution of Black Soils

- Spread over **5.46 lakh sq km (16.6 per cent of the total area) across** Maharashtra, Madhya Pradesh, parts of Karnataka, Telangana, Andhra Pradesh, Gujarat and Tamil Nadu.

Crops in Black Soils

- These soils are best suited for cotton crop. Hence these soils are called as **regur and black cotton soils.**
- Other major crops grown on the black soils include wheat, jowar, linseed, virginia tobacco, castor, sunflower and millets.
- Rice and sugarcane are equally important where irrigation facilities are available.
- Large varieties of vegetables and fruits are also successfully grown on the black soils.
- This soil has been used for growing a variety of crops for centuries without adding fertilizers and manures, with little or no evidence of exhaustion.

Indian Soil Types: Red Soils, Laterite – Lateritic Soils, Forest – Mountain Soils, Arid – Desert Soils, Saline – Alkaline Soils, Peaty – Marshy Soils.

Previous post: Alluvial Soil – Black Soil.

Red Soils

- Red soils along with its minor groups form the **largest soil group of India.**

- The main parent rocks are crystalline and **metamorphic rocks** like acid granites, gneisses and quartzites.

Characteristics of Red Soils

- The texture of these soils can vary from sand to clay, the majority being loams.
- On the uplands, the red soils are poor, gravelly, and porous. But in the lower areas they are rich, deep dark and fertile.

Chemical Composition of Red Soils

- They are **acidic** mainly due to the nature of the parent rocks. The alkali content is fair.
- They are poor in lime, magnesia, **phosphates, nitrogen** and humus.
- They are fairly rich in **potash and potassium.**

Color of Red Soils

- The red colour is due to the presence of **iron oxide.**
- When limestone, granites, gneisses and quartzites are eroded the clay enclosed within the rocks remains intact with other forms of non-soluble materials.
- In oxidizing conditions, rust or iron oxide develops in the clay, when the soil is present above the water table giving the soil a characteristic red colour.
- The colour is more due to the **wide diffusion** rather than high percentage of iron oxide content.

Distribution of Red Soils

- These soils mostly occur in the regions of low rainfall.
- They occupy about 3.5 lakh sq km (10.6 per cent) of the total area of the country.
- These soils are spread on almost the whole of **Tamil Nadu.**
- Other regions with red soil include parts of Karnataka, south-east of Maharashtra, Telangana, Andhra Pradesh, Madhya Pradesh, Chhattisgarh, Odisha, Chota Nagpur plateau; parts of south Bihar, West Bengal, Uttar Pradesh; Aravalis and the eastern half of Rajasthan (Mewar or Marwar Plateau), parts of North-Eastern states.

Crops in Red Soils

- The red soils are **mostly loamy** and hence **cannot retain water** like the black soils.
- The red soils, with the proper use of fertilizers and irrigation techniques, give good yield of cotton, wheat, rice, pulses, millets, tobacco, oil seeds, potatoes and fruits.

Laterite – Lateritic Soils

- Laterite soils are mostly the **end products of weathering.**
- They are formed under conditions of **high temperature and heavy rainfall** with alternate wet and dry periods.
- Heavy rainfall promotes **leaching (nutrients gets washed away by water)** of soil whereby lime and silica are leached away and a soil rich in oxides of iron and aluminium compounds is left behind.
- 'Laterite' means brick in Latin. They harden greatly on loosing moisture.
- Laterite soils are red in colour due to little clay and more gravel of red sand-stones.

Chemical composition of Laterite – Lateritic Soils

- Laterite soils are rich in **bauxite or ferric oxides.**
- They are very **poor** in lime, magnesia, **potash and nitrogen.**
- Sometimes, the **phosphate** content may be **high** in the form of **iron phosphate.**
- In wetter places, there may be higher content of humus.

Distribution of Laterite – Lateritic Soils

- Laterite soils cover an area of 2.48 lakh sq km.
- Continuous stretch of laterite soil is found on the summits of Western Ghats at 1000 to 1500 m above mean sea level, Eastern

Ghats, the Rajmahal Hills, Vindhyan, Satpuras and Malwa Plateau.

- They also occur at lower levels and in valleys in several other parts of the country.
- They are well developed in south Maharashtra, parts of Karnataka etc. and are widely scattered in other regions.

Crops in Laterite – Lateritic Soils

- Laterite soils lack fertility due to **intensive leaching.**
- When manured and irrigated, some laterites are suitable for growing **plantation crops** like tea, coffee, rubber, cinchona, coconut, arecanut, etc.
- In some areas, these soils support **grazing grounds and scrub forests.**

Economic value of Laterite – Lateritic Soils

- Laterite and lateritic soils provide **valuable building material.**
- These soils can be easily cut into cakes but hardens like iron when exposed to air.
- As it is the end-product of weathering, it cannot be weathered much further and is durable.

Forest – Mountain Soils

- These soils occupy about 2.85 lakh sq km or 8.67% of the total land area of India.
- They are mainly **heterogeneous soils** found on the hill slopes covered by forests.
- The formation of these soils is mainly governed by the characteristic deposition of organic matter derived from forests and their **character changes with parent rocks**, ground-configuration and climate.
- Consequently, they **differ greatly even if they occur in close proximity to one another.**

Distribution of Forest – Mountain Soils

- In the Himalayan region, such soils are mainly found in valleys, less steep and north facing slopes. The south facing slopes are very steep and exposed to denudation and hence do not support soil formation.
- Forest soils occur in Western and Eastern Ghats also.

Chemical properties of Forest – Mountain Soils

- The forest soils are very **rich in humus.**
- They are deficient in potash, phosphorus and lime.
- They require good deal of fertilizers for high yields.

Crops in Forest – Mountain Soils

- They are suitable for **plantations** of tea, coffee, spices and tropical fruits in peninsular forest region.
- Wheat, maize, barley and temperate fruits are grown in the Himalayan forest region.

Arid – Desert Soils

- The desert soils consist of **Aeolian sand** (90 to 95 per cent) and clay (5 to 10 per cent).
- They cover a total area of 1.42 lakh sq km (4.32%).
- The presence of sand inhibits soil growth. Desertification of neighboring soils is common due to intrusion of desert sand under the influence of wind [Aeolian sand].

Distribution of Arid – Desert Soils

- Occur in arid and semi-arid regions of Rajasthan, Punjab and Haryana. The sand here is blown from the Indus basin and the coast by the prevailing south-west monsoon winds.
- Sandy soils without clay factor are also common in coastal regions of Odisha, Tamil Nadu and Kerala.

Chemical properties of Arid – Desert Soils

- They are usually poor in organic matter.

- Some desert soils are **alkaline** with varying degree of soluble salts like **calcium carbonate.**
- Calcium content increases downwards and the subsoil has ten times more calcium.
- The **phosphate** content of these soils is as **high** as in normal alluvial soils.
- Nitrogen is originally low but some of it is available in the **form of nitrates.**

Crops of Arid – Desert Soils

- Phosphates and nitrates make these soil fertile wherever moisture is available.
- There is a possibility of reclaiming these soils if proper irrigation facilities are available.
- In large areas, only the drought resistant and salt tolerant crops such as barley, cotton, millets, maize and pulses are grown.

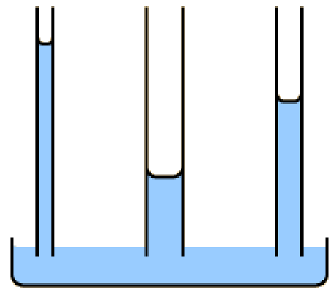
Saline – Alkaline Soils

- In Saline and Alkaline Soils, the top soil is **impregnated** (soak or saturate with a substance) with saline and alkaline efflorescences (become covered with salt particles).
- Undecomposed rock fragments, on weathering, give rise to **sodium, magnesium and calcium salts and sulphurous acid.**
- Some of the salts are transported in solution by the rivers.
- In regions with low water table, the salts percolate into sub soil and in regions with good drainage, the salts are wasted away by flowing water.
- But in places where the drainage system is poor, the water with high salt concentration becomes stagnant and deposits all the salts in the top soil once the water evaporates.
- In regions with high sub-soil water table, injurious salts are transferred from below by the **capillary action** as a result of evaporation in dry season.

Capillary action

Capillary action is the ability of a liquid to flow in narrow spaces without the assistance of, and in opposition to, external forces like gravity.

The force behind capillary action is **surface tension.**

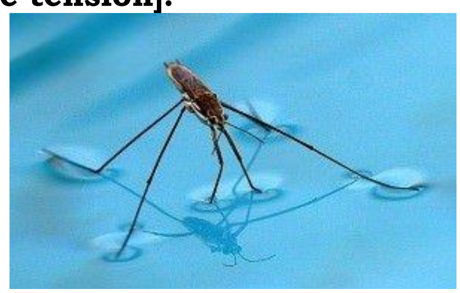


Surface tension

Surface tension is the elastic tendency of liquids (a membrane like surface) that makes them acquire the least surface area possible.

Surface tension causes insects (e.g. water striders), usually denser than water, to float and stride on the water surface.

Surface tension offers the necessary buoyant force (buoyancy) required for an object to float in water **[Ships flots because of difference in density as well surface tension].**



What gives water droplet its shape?

When a water droplet is freely falling, it acquires a spherical shape.

When a water drop is on a surface, it acquires the shape of a hemisphere (half a sphere).

All this is due to **surface tension.**

This kind of trivial GK can help in many exams.

Distribution of Saline – Alkaline Soils

- Saline and Alkaline Soils occupy 68,000 sq km of area.
- These soils are found in canal irrigated areas and in areas of high sub-soil water table.
- Parts of Andhra Pradesh, Telangana, Karnataka, Bihar, Uttar Pradesh, Haryana, Punjab (side effects of improper or excess irrigation), Rajasthan and Maharashtra have this kind of soils.
- The accumulation of these salts makes the soil infertile and renders it unfit for agriculture.
- In Gujarat, the areas around the Gulf of Khambhat are affected by the **sea tides** carrying salt-laden deposits. Vast areas comprising the estuaries of the Narmada, the Tapi, the Mahi and the Sabarmati have thus become infertile.
- Along the coastline, saline sea waters infiltrate into coastal regions during **storm surges** (when cyclones make landfall) and makes the soil unfit for cultivation. The low lying regions of coastal Andhra Pradesh and Tamil Nadu face this kind of soil degradation.

Peaty – Marshy Soils

- These are soils with **large amount of organic matter** and **considerable amount of soluble salts.**
- The most humid regions have this type of soil.
- They are black, heavy and **highly acidic.**

Distribution of Peaty – Marshy Soils

- Kottayam and Alappuzha districts of Kerala where it is called kari.
- Also occur in the coastal areas of Odisha and Tamil Nadu, Sunderbans of West Bengal, in Bihar and Almora district of Uttarakhand.

Chemical Properties of Peaty – Marshy Soils

- They are deficient in potash and phosphate.

Crops of Peaty – Marshy Soils

- Most of the peaty soils are under water during the rainy season but as soon the rains cease, they are put under paddy cultivation.

Characteristics of Indian Soils

- Most soils are old and mature. Soils of the peninsular plateau are much older than the soils of the great northern plain.
- Indian soils are largely **deficient in nitrogen, mineral salts, humus and other organic materials.**
- Plains and valleys have thick layers of soils while hilly and plateau areas depict thin soil cover.
- Some soils like alluvial and black soils are fertile while some other soils such as laterite, desert and alkaline soils lack in fertility and do not yield good harvest.
- Indian soils have been used for cultivation for hundreds of years and have **lost much of their fertility.**

Problems Of Indian Soils

- Soil erosion (Himalayan region, Chambal Ravines etc.), deficiency in fertility (Red, lateritic and other soils), desertification (around Thar desert, rain-shadow regions like parts of Karnataka, Telangana etc.), waterlogging (Punjab-Haryana plain) salinity and alkalinity (excessively irrigated regions of Punjab, Haryana, Karnataka etc.), wasteland, over exploitation of soils due to increase in population and rise in living standards and encroachment of agricultural land due to urban and transport development.

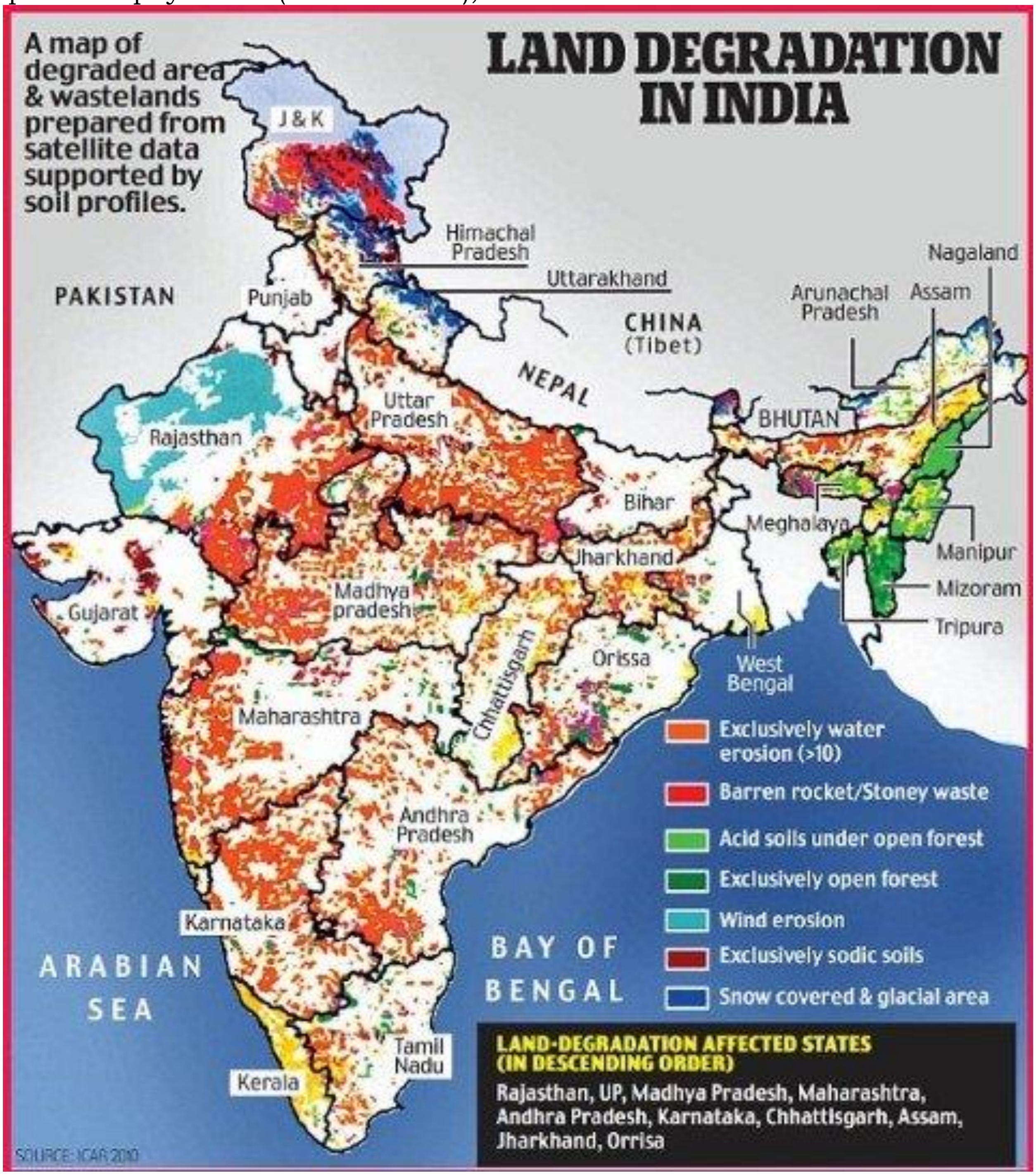
Soil Degradation – Soil Erosion, Deforestation, Overgrazing, Faulty Methods of Agriculture, Soil Salinity and Soil Alkalinity, Desertification & Waterlogging.

Soil Degradation

- Soil degradation is the decline in soil quality caused by its improper use, usually for agricultural, pastoral, industrial or urban purposes.
- Soil degradation is a serious global environmental problem and may be exacerbated by climate change. It encompasses physical (soil erosion), chemical (salinity and alkalinity, pollution) and biological deterioration (pollution and deterioration of vegetal cover).

We will see pollution and soil degradation white studying environment.

For now we will study about the rest.



Pic: http://www.dailymail.co.uk/

Soil Erosion

- Soil erosion is the removal of top soil by agents like wind and water.
- Top soil has most of the nutrients necessary for a plant's growth. With

depth, the fertility of the soil decreases. Thus, erosion results in reduction of fertility of the soil by washing away the fertile top layer.

- Erosion by wind and water is much quicker than the soil formation process. So once fertile soil layer is lost, it requires a lot of time and resources to restore it.
- Prevention is a more practical measure. It is less time and resource consuming.
- In India's case, the problem of soil erosion is particularly severe due to over dependence on agriculture and improper land management.
- Notable Quotable: **"Soil erosion is essentially a problem created by man and also faced by man himself."**

Water Erosion

- Water erosion leads to rilling, gullying, sheet-wash and rain peeling.
- If erosion continues unchecked for a long time, numerous finger-shaped grooves may develop in the silt laden soils. The whole pattern resembles the shape of a tree. This is called **rill erosion.**
- With further erosion of the soil, the rills deepen and become enlarged and are turned into **gullies.** Gullies formed over a large area gives rise to **badland topography (Chambal Ravines).**
- When a gully bed is eroded further, the bed gradually deepens and flattens out and a **ravine** is formed. The depth of a ravine may extend to 30 metres or more.
- Further erosion of ravine beds gives rise to **canyons.** Canyons are few hundred meters deep and wide. (Grand Canyon on Colorado River).
- When the entire top sheet of soil is washed away by water or by wind, leaving behind barren rock, it is called **sheet erosion.** Sheet erosion attacks a large area of top soil and renders the land almost unfit for cultivation.
- In the coastal areas, waves dash along the coast and cause heavy damage to soil. During the landfall of cyclones, storm surges destroy beaches and wash away the top layer. In estuaries, tidal bores cause extensive damage to the surrounding banks. This is called **sea erosion.**
- In the higher reaches of the Himalayan region, soil erosion is caused by sowing moving glaciers. This is called **glacial erosion.**

Wind Erosion

- Wind erosion or **Aeolian erosion** is quite significant in arid and semi-arid regions.
- Winds usually blow at high speeds in deserts due to absence of trees (physical obstruction).
- These winds remove the fertile, arable, loose soils leaving behind a depression devoid of top soil (the depression formation in deserts is the first step in Oasis formation. Oasis forms in depressions when there is underground water that gets accumulated above rocks).
- Desertification around desert regions is due to wind erosion.
- Wind erosion is accentuated when the soil is dry, soils are subjected to overgrazing and devoid of vegetation cover.
- Very fine and medium sands are moved by wind in a succession of bounds and leaps, known as **saltation.**
- Coarse sand is not usually airborne but rather is rolled along the soil surface. This type of erosion is called **surface creep.**
- Very coarse sand and gravels are too large to be rolled by wind, so wind-eroded soils have surfaces covered with coarse fragments larger than 1.00 mm in diameter. This kind of arid soil surface is known as **desert pavement.**

Extent Of Soil Erosion In India

- 80 million hectares or about one-fourth of our total area is exposed to wind and water erosion.
- One-eighth of land has undergone serious erosion.
- Wind erosion is a serious problem in arid and semi-arid parts of north west India.

- About one-ninth of land is subject to severe wind erosion in Rajasthan and adjoining areas of Punjab, Haryana, Gujarat and Western Uttar Pradesh.
- It is estimated that 34 lakh tonnes of fertile soils is removed by wind every year.
- The loss due to water erosion is 53.34 million hectares annually.

Factors affecting Soil Erosion

- Intensity and duration of rainfall,
- Wind speed,
- Nature of soil and the physiography,
- Strong winds in dry areas,
- Human density,
- Deforestation,
- Overgrazing,
- Faulty methods of agriculture,
- Diversion of natural drainage courses,
- Wrong orientation of roads and railways, embankments and bridges.

Effects of Soil Erosion

- Fertile top soil is eroded.
- Flooding and leaching result in loss of mineral nutrients.
- Ground water level is lowered.
- There is decrease in soil moisture.
- Desertification.
- Frequency and intensity of floods and drought increases.
- Rivers, canals and tanks are silted and their water holding capacity decreases.
- The incidence and damaging power of landslides increases.

Deforestation

- Population explosion has created pressure on forest land and resources and this causes deforestation. Deforestation accentuates soil erosion (soil degradation).
- Roots of trees and plants bind the soil particles and regulate the flow of water, thus saving soil from erosion. Deforestation make soil vulnerable to wind and water erosion.
- The large scale damage to soil in Shiwalik range, the **Chos of Punjab**, the ravines of Chambal valley are due to deforestation.

Major Causes of Deforestation

- Indiscriminate felling of trees as a result of agricultural operations, urbanization, industrialization, infrastructure development, mining operations, and use of wood for domestic and other purposes, have resulted in depletion of forests.

Shifting cultivation

- In this practice a patch of land is cleared, vegetation is burned and the ash is mixed with the soil thus adding nutrients to the soil.
- This patch of land is used for raising crops for two to three years, and the yield is modest.
- Then this area is abandoned and is left to recover its fertility, and the same practice is repeated elsewhere on a fresh piece of land.
- This agricultural practice has become totally unsustainable due to raid increase in population pressure in the forested areas.

Development project and Mining

- Population pressure and development agenda have resulted in indiscriminate development of infrastructure, water reservoirs and dams, hydro power projects, roads and railways etc. This led to greater deforestation.
- Open cast mining has resulted in deforestation all over the world.

Plantation Boom

- Increase in demand for cocoa, coffee, tea, sugar, palm oil, rubber etc. have resulted in deforestation in the tropical rainforests.

Fuel Requirements

- The increasing demand for firewood with ever. growing population increases greater pressure on the forests, which results in increased intensity of deforestation.

Demand for Forest Resources

- Population pressure coupled with changes in standard of living have increased the demand for forest resources.

Raw Materials

- Wood is used as a raw material by various industries for making paper, plywood, furniture, match sticks, boxes, crates, packing cases, etc.
- Industries also obtain their raw materials from plants such as drugs, scents and perfumes, resin, gums, waxes, turpentine, latex and rubber, tannis, alkaloids, bees wax.
- This exerted tremendous pressure on forest ecosystem and their unrestricted exploitation for various other raw materials is the main cause of degradation of the forest ecosystem.

Other Causes

- Deforestation also results from overgrazing, agriculture, mining, urbanization, flood, fire, pest, diseases, defense and communication activities.

Effects of Deforestation

- Closed forests (based on canopy level) have being diminished due to deforestation leading to increase in degraded forests.
- Forests recycle moisture (natural motors) from soil into their immediate atmosphere by transpiration where it again precipitates as rain.
- Deforestation results in an immediate lowering of ground water level (low percolation due to quick surface runoff on barren lands) and in long-term reduction of precipitation.
- Due to deforestation, this natural reuse cycle is broken and water is lost through rapid run off.
- Much of the mining activity in India is being carried out in forest regions. The obvious result is deforestation and soil erosion.
- Underground mining also significantly denudes forests because timber is used for supporting the roofs of mine galleries.
- A large number of abandoned mines are lying in bad shape and are under extensive gully erosion leading to degradation of the habitat.
- Deforestation affects the biota and neighboring ecosystems, soil erosion, land degradation, alteration of ground water channels, pollution and scarce.

Overgrazing

- During the rainy season, there is plenty of vegetation and animals get enough fodder.
- But during the dry period, there is shortage of fodder and the grass is grazed to the ground and torn out by the roots by animals.
- This leads to loose structure of the soil and the soil is easily washed away by rains.
- Moreover, soil is pulverized (reduce to fine particles) by the hoofs of animals, and thus proves detrimental to top soil when heavy showers fall on it.
- Soil erosion due to overgrazing is a common site in the hilly areas.

Faulty Methods of Agriculture

- Much of the soil erosion in India is caused by faulty methods of agriculture.
- Wrong ploughing, lack of crop rotation and practice of shifting cultivation are the most adversely affecting methods of agriculture.
- If the fields are ploughed along the slope, there is no obstruction to the flow of water and the water washes away the top soil easily.
- In some parts of the country, the same crop is grown year after year which spoils the chemical balance of the soil. This soil is exhausted and is easily eroded by wind or water.

- Shifting cultivation practiced in some areas in the north-eastern states. In this method, a piece of forest land is cleared by felling and burning of trees and crops are grown. The removal of the forest cover leads to the exposure of the soil to rains and sun which results in heavy loss of top soil, especially on the hill slopes.

Soil Salinity and Soil Alkalinity

- In Saline and Alkaline Soils, the top soil is **impregnated** (soak or saturate with a substance) with saline and alkaline efflorescences (become covered with salt particles).
- Undecomposed rock fragments, on weathering, give rise to **sodium, magnesium and calcium salts and sulphurous acid.**
- Some of the salts are transported in solution by the rivers.
- In regions with low water table (due to over irrigation in canal irrigated areas), the salts percolate into sub soil and in regions with good drainage, the salts are wasted away by flowing water.
- But in places where the drainage system is poor, the water with high salt concentration becomes stagnant and deposits all the salts in the top soil once the water evaporates.
- In regions with high sub-soil water table, injurious salts are transferred from below by the **capillary action** as a result of evaporation in dry season.
- In canal irrigated areas plenty of the water is available and the farmers indulge in over irrigation of their fields.
- Under such conditions, the ground water level rises and saline and alkaline efflorescences consisting of salts of sodium, calcium and magnesium appear on the surface as a layer of white salt through capillary action.
- Alkalinity implies the dominance of sodium salts, specially **sodium carbonate.**
- Although salts of alkali are somewhat different in their chemical properties from the salts of saline soils both soils occur in the same areas.
- Sandy soils are more prone to alkalinity and the loamy soils to salinity-alkalinity.
- It is estimated that about 80 lakh hectares of land (2.43% of the country's total area) is affected by the problem of salinity and alkalinity.
- Vast tracts of canal irrigated areas in Uttar Pradesh. Punjab and Haryana; arid regions of Rajasthan, semi-arid areas of Maharashtra, Gujarat, Andhra Pradesh, Telangana and Karnataka etc. are facing this problem.
- Although Indira Gandhi canal in Rajasthan has turned the sandy desert into a granary, it has given birth to serious problems of salinity and alkalinity.

Effects of salinity and alkalinity

- Salinity and alkalinity have adverse effect on soil and reduce soil fertility.
- Cultivation is not possible on saline soils unless they are flushed out with large quantities of irrigation water to leach out the salts.
- Choice of crops is limited to salinity tolerant crops like cotton, barley etc..
- Quality of fodder and food produced in poor in quality.
- Salinity and alkalinity create difficulties in building and road construction.
- These cause floods due to reduced percolation of water.

Steps to treat salinity and alkalinity

- Providing outlets for lands to drain out excess water and lower water table.
- Seal leakages from canals, tanks and other water bodies by lining them.
- Making judicious use of irrigation facilities.
- Improve vegetal cover to avoid further degradation by planting salt tolerant vegetation.
- Crop rotation..
- Liberal application of gypsum to convert the alkalies into soluble compounds.

- Alkali can be removed by adding sulphuric acid or acid forming substances like sulphur and pyrite.
- Organic residues such as rice husks and rice straw can be added to promote formation of mild acid as a result of their decomposition.
- Flushing the salt by flooding the fields with excess water. However, this practice can lead to accumulation of saline water in the downstream area.

Desertification

- Desertification is the spread of desert like conditions in arid or semi-arid areas due to man's influence or climatic change.
- A large part of the arid and semi-arid region lying between the Indus and the Aravali range is affected by spreading desert conditions.
- Desert soils suffer maximum erosion by wind. The sand carried by wind is deposited on the adjoining fertile lands whose fertility dwindles and slowly the fertile land start merging with the advancing desert.
- It has been estimated that the Thar Desert is advancing at an alarming rate of about 0.5 km per year.
- The process of desertification is attributed to uncontrolled grazing, reckless felling of trees and growing population. Climate change have also contributed to the spread of deserts.

Ecological implications of desertification

- Drifting of sand and its accumulation on fertile agricultural land.
- Excessive soil erosion by wind and to some extent by water.
- Deposition of sand in rivers, lakes and other water bodies thereby decreasing their water containing capacity.
- Lowering of water table leading to acute water shortage.
- Increase in area under wastelands.
- Decrease in agricultural production.
- Increase in frequency and intensity of droughts.

Measures of Controlling Desertification

- Intensive tree plantation in the transition zones.
- Mulching shifting sand dunes in deserts with different plant species. Mulches serve as an effective physical barrier to the moving sand.
- Grazing should be controlled and new pastures should be developed.
- Indiscriminate felling of trees should be banned.
- Alternative sources of fuel can reduce the demand for fuelwood.
- Sandy and wastelands should be put to proper use by judicious planning.

Waterlogging

- The flat surfaces and depressions results in waterlogging.
- Waterlogged soils are soaked with water accumulated during rainy season or due to leakage from various water sources.
- Extent of waterlogged soils is about 12 million hectares in India – half of which lies along the coast and the other half in the inland area.
- Waterlogging is believed to be one of the chief causes of salinity.
- Proper layout of drainage schemes is the only way to overcome the menace of waterlogging.
- The basic methods of removing excess water from waterlogged soils are (a) surface drainage and (b) vertical drainage.

(a) Surface Drainage. Surface drainage involves the disposal of excess water over ground surface through an open drainage system with an adequate outlet.

(b) Vertical Drainage. Any bore or well from which the underlying water is extracted is defined as vertical drainage. It works well in Indo-Gangetic plain where the pumped water is used for irrigating the neighboring regions.

Soil Conservation – Crop Rotation, Strip Cropping, Use of Early Maturing Varieties, Contour Ploughing, Checking Shifting Cultivation, Ploughing the Land in Right Direction, Mulching, Contour barriers, Terrace farming, Contour Bunding, Intercropping, Contour ploughing, Shelter belts or Windbreaks, Sand fences, Afforestation, Checking Overgrazing.

Soil Conservation

- Soil conservation is the prevention of soil from erosion or reduced fertility caused by overuse, acidification, salinization or other chemical soil contamination.
- Soil erosion is the greatest single evil to Indian agriculture and animal husbandry.
- Notable Quotable from Kullar's Indian Geography: "With soil conservation people rise and with its destruction they fall. Neglect of soil is like killing the hen that lays the golden egg."

Crop Rotation

- Adopting sustainable agricultural practices is the most important measure to conserve soil.
- In many parts of India, a particular crop is sown in the same field year after year. This practice leads to exhaustion of certain nutrients in the soil making it infertile.
- Crop rotation is a practice in which a different crop is cultivated on a piece of land each year.
- This helps to conserve soil fertility as different crops require different nutrients from the soil. Crop rotation will provide enough time to restore lost nutrients.
- For example, potatoes require much potash but wheat requires nitrate. Thus it is best to alternate crops in the field.
- Legumes such as peas, beans, and many other plants, add nitrates to the soil by converting free nitrogen in the air into nitrogenous nodules on their roots. Thus if they are included in the crop rotation nitrogenous fertilizers can be dispensed with.

Strip Cropping

- Crops may be cultivated in alternate strips, parallel to one another. Some strips may be allowed to lie fallow while in others different crops may be sown.
- Various crops are harvested at different intervals. This ensures that at no time of the year the entire area is left bare or exposed.
- The tall growing crops act as wind breaks and the strips which are often parallel to the contours help in increasing water absorption by the soil by slowing down run off.

Use of Early Maturing Varieties

- Early maturing varieties of crops take less time to mature and thus put lesser pressure on the soil. In this way it can help in reducing the soil erosion.

Contour Ploughing

- If ploughing is done at right angles to the hill slope, the ridges and furrows break the flow of water down the hill.
- This prevents excessive soil loss as gullies are less likely to develop and also reduce run-off so that plants receive more water.

Checking Shifting Cultivation

- Checking and reducing shifting cultivation by persuading the tribal people to switch over to settled agriculture is a very effective method of soil conservation.
- This can be done by making arrangements for their resettlement which involves the provision of residential accommodation, agricultural implements, seeds, manures, cattle and reclaimed land.

Ploughing the Land in Right Direction

- Ploughing the land in a direction perpendicular to wind direction also reduces wind velocity and protects the top soil from erosion.

Mulching

- The bare ground (top soil) between plants is covered with a protective layer of organic matter like grass clippings, straw, etc.

Benefits

- Protects the soil from erosion.
- It helps to retain soil moisture.
- Reduces compaction from the impact of heavy rains.
- Conserves moisture, reducing the need for frequent watering.
- Maintains a more even soil temperature.
- Prevents weed growth.
- Organic mulches also improve the condition of the soil. As these mulches slowly decompose, they provide organic matter which helps keep the soil loose.

Contour barriers

- Stones, grass, soil are used to build barriers along contours. Trenches are made in front of the barriers to collect water.
- They intercept downslope flowing water and soil particles. These barriers slow down the water movement and reduce its erosive force. They also filter out and trap many of the suspended soil particles, keeping them from being washed out of the field.
- A long term advantage of barriers is that soil tends to build up behind them, creating a terrace effect. Barriers can be classified as live (strips of living plants), dead (rocks, crop residues), or mixed (a combination of the previous two).

Rock dam

- Rocks are piled up across a channel to slow down the flow of water. This prevents gullies and further soil loss.

Terrace farming

- In terracing, a number of terraces are cut along the hill slope.
- These are made on the steep slopes so that flat surfaces are available to grow crops. They can reduce surface run-off and soil erosion.

Fig 2.5: Terrace Farming

Fig 2.6: Contour Ploughing

Contour Bunding

- Contour bunding involves the construction of banks along the contours.
- Terracing and contour bunding which divide the hill slope into numerous small slopes, check the flow of water, promote absorption of water by soil and save soil from erosion.
- Retaining walls of terraces control the flow of water and help in reducing soil erosion.

Intercropping

- Different crops are grown in alternate rows and are sown at different times to protect the soil from rain wash.

Contour ploughing

- Ploughing parallel to the contours of a hill slope to form a natural barrier for water to flow down the slope

Shelter belts or Windbreaks

- In the coastal and dry regions, rows of trees are planted to check the wind movement to protect soil cover.

Fig 2.7: Shelter Belts

Sand fences

- Sand fences are barriers made of small, evenly spaced wooden slats or fabric. They are erected to reduce wind velocity and to trap blowing sand. Sand fences can be used as perimeter controls around open construction sites to keep sediments from being blown offsite by the wind.

Afforestation

- It includes the prevention of forest destruction along with growing new forests or increase area under forests.
- A minimum area 20 to 25 per cent of forest land was considered healthy for soil and water conservation for the whole country.
- It was raised to 33 per cent in the second five year plan – 20 per cent for the plains and 60 per cent for hilly and mountainous regions.

Checking Overgrazing

- Overgrazing accentuates erosion. During the dry period, there is shortage of fodder and the grass is grazed to the ground and torn out to the roots by animals. Soil is pulverized (reduce to fine particles) by the hoofs of animals. All this leads to weak top layer.
- So overgrazing needs to be checked to prevent soil erosion.
- This can be done by creating separate grazing grounds and producing larger quantities of fodder.

Dams

- Much of the soil erosion by river floods can be avoided by constructing dams across the rivers in proper places. This checks the speed of water and saves soil from erosion.
- But indiscriminate dam construction can worsen the condition by creating floods and landslides like it happens in the Himalayan region.

Economic Geography

Iron Ore – Raw Material, Commonly found impurities in Iron Ore, What exactly happens in a blast furnace? Beneficiation. Iron Ore Distribution Across the World.

Factors that influence the location of Iron and Steel industry

- Raw materials – iron ore, coal, limestone, etc.
- Transportation and other infrastructure – road, rail, ports etc.
- Investment and Entrepreneurship = banking facilities, human capital for managerial roles.
- Land.
- Labour – unskilled to semi-skilled workforce for manual operations, skilled workforce for technical operations.
- Market – construction industry, automobile industry etc.
- Government policy – Development agenda, land acquisition, ease of doing business = labor laws, unambiguous and fair taxation policy, least government interference, less red tapeism, quick environmental clearance [Read more from: www.mrunal.org/geography].

Iron Ore – Raw Material

The below data is important for Prelims [Will be helpful to answer some logic based questions in mains]

- To understand about the factors that influence the location of Iron and Steel Industry, we have to understand about iron ore smelting.
- **Smelting** is a process of converting ore to metal by removing impurities.

Commonly found impurities in Iron Ore

Silicon

- Found in small quantities.
- Slightly raises the Strength and Hardness of Steel.
- Acts as a **de-oxidizing Agent** ==> small quantities is good. [Oxides decrease the strength of Iron]

Sulphur

- A **VERY harmful element**.
- Forms Iron Sulphide which is a very **brittle** substance.
- Greatly reducing the Strength of Steel ==> very bad.

Phosphorous

- Combines with Iron to form a Phosphide.
- It increases the hardness and Tensile strength of Steel.
- It SERIOUSLY affects the ductility and resistance to shock or impact ==> bad.

Lead

- Added to all classes of Steel to improve the **machinability of the Steel**.
- It **improves tool life** ==> small quantities is good.

Manganese

- A **powerful and most effective de-oxidant**.
- Has a good effect on Sulphur ==> small quantities is good.

Tin

- It forms a low melting point brittle film round the grain boundaries making the Steel **practically useless** ==> very bad.

Oxygen

- Has a bad influence on the properties of steel ==> very bad. **[Oxides make Iron and steel weak]**

Of the impurities, some are beneficial when present in small quantities while the others are harmful no matter what their proportion is.

So, the unwanted impurities must be removed and this is done by **smelting iron ore in a blast furnace.**

What exactly happens in a blast furnace?

- In a blast furnace, **fuel (coke), iron ore, and flux (limestone)** are continuously supplied through the top of the furnace.
- A hot blast of air (sometimes with oxygen enrichment) is blown into the lower section.
- In a blast furnace, iron oxides are converted into liquid iron called "hot metal".

[Oxides make iron brittle. To make iron strong the oxides need to be removed]

Inputs in to blast furnace

- Ore ➔ iron ore,
- Fuel ➔ coke,
- Flux ➔ limestone,

Output

- Final product ➔ **liquid slag**, **liquid iron (pig iron)** and gases.

Beneficiation = Improve Concentration of Iron

- Ore is either Hematite (Fe_2O_3) or Magnetite (Fe_3O_4) and the iron content ranges from 50% to 70%.
- This iron rich ore can be charged directly into a blast furnace without any further processing.
- Iron ore that contains a lower iron content must be processed or **beneficiated to increase its iron content.**

[Beneficiation ➔ Improves the concentration of iron ore]

Why coke and not coal in smelting?

- To separate impurities, iron needs to be melted.
- The coke is the fuel that melts iron.
- Coal has many impurities and the most dangerous one is **SULPHUR.**
- Coal is cooked to produce coke. This process is called **destructive distillation**.
- Coke is a fuel with **few impurities and a high carbon content**.
- The cooked coal, called coke contains 90 to 93% carbon, some ash and sulfur but compared to raw coal is very strong.

Role of limestone = Remove Sulphur

- It is acts as flux **(a substance mixed with a solid to lower the melting point, especially in smelting).**
- Limestone melts and reacts with Sulphur to form Slag (All solid and liquid impurities).

[Limestone marries Sulphur and takes it away from Iron == Very Good]

$CaCO_3 = CaO + CO_2$

The CaO formed from this reaction is used to remove sulfur from the iron.

$FeS + CaO + C = CaS + FeO + CO$

- The **CaS** [newly married couple] becomes part of the slag.
- The slag is also formed from any remaining Silica (SiO_2), Alumina (Al_2O_3), Magnesia (MgO) or Calcia (CaO) that entered with the iron ore or coke.
- The liquid slag then trickles to the bottom of the furnace where it **floats on top of the liquid iron** since it is less dense.

Reduction = Remove Oxygen

- Oxygen in the iron oxides is reduced (removed) by a series of chemical reactions.

1) $3Fe_2O_3 + CO = CO_2 + 2Fe_3O_4$
2) $Fe_3O_4 + CO = CO_2 + 3\ FeO$
3) $FeO + CO = CO_2 + Fe$

CO or **CARBON MONOXIDE** is produced by burning coke.

So CO and CO_2 are the gaseous pollutants coming out of blast furnace.

Pig Iron

- Pig iron is the intermediate product of smelting iron ore.
- Iron (Fe) = 93.5 - 95.0%
- Silicon (Si) = 0.30 - 0.90%
- Sulfur (S) = 0.025 - 0.050%
- Manganese (Mn) = 0.55 - 0.75%
- Phosphorus (P) = 0.03 - 0.09%
- Titanium (Ti) = 0.02 - 0.06%
- ***CARBON (C)= 4.1 - 4.4%*** [The strength of steel can be varied by varying the carbon content]

Cast iron

- Carbon content **greater than 2%.**
- Carbon (C) and silicon (Si) are the main alloying elements.
- Cast iron tends to be **brittle.**
- Applications: automotive industry parts, cast iron pan.

Steel

- Carbon content is **up to 2.1% (by weight).**

Stainless steel

- Steel alloy with a minimum of **10.5% chromium** content by mass.
- **Nickel** is another important element of steel alloy.
- Also contains **manganese, molybdenum**, and other metals.
- Stainless steel **does not readily corrode**, rust or stain with water as ordinary steel does.

Wrought iron

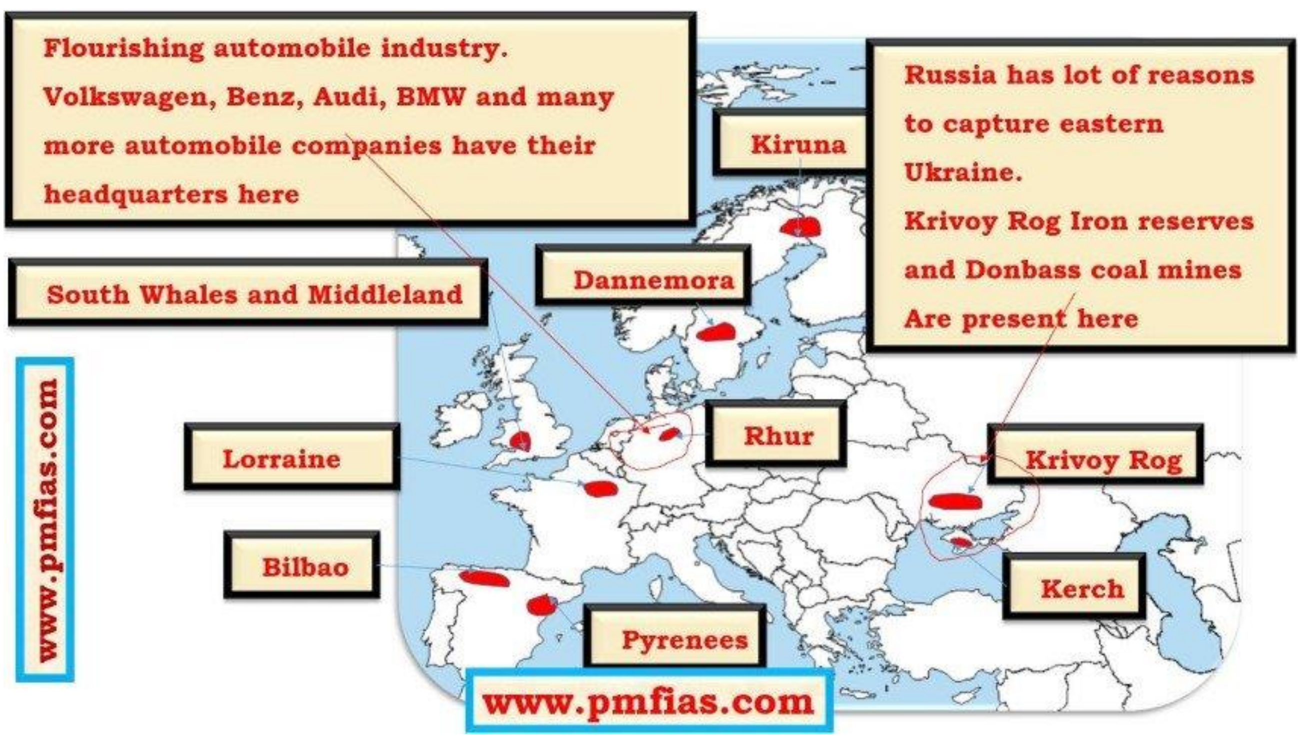
- Cast iron assumes its finished shape the moment the liquid iron alloy cools down in the mold.
- Wrought iron is a very different material made by **mixing liquid iron with some slag.**

- The result is an iron alloy with a **much lower carbon content**.
- Wrought iron is softer than cast iron and much less tough, so you can heat it up to shape it relatively easily, and it's also much less prone to rusting.
- Wrought iron is what people used to use before they really mastered making steel in large quantities in the mid-19th century.

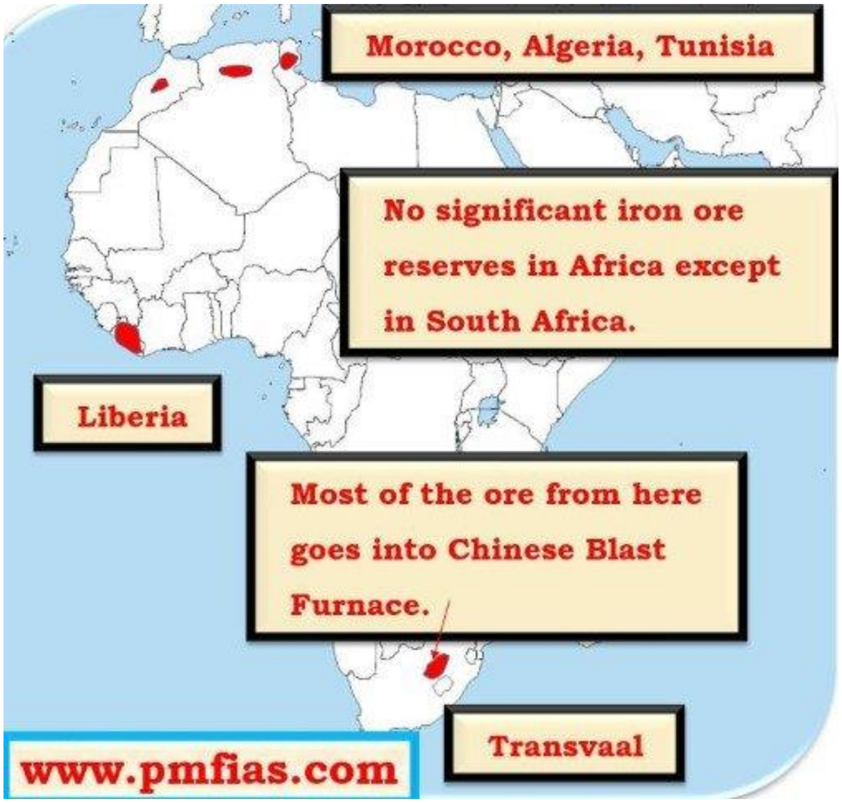
Iron Ore Distribution Across the World

Iron Ore in China – Manchuria, Sinkiang, Si-kiang, Shandog Peninsula

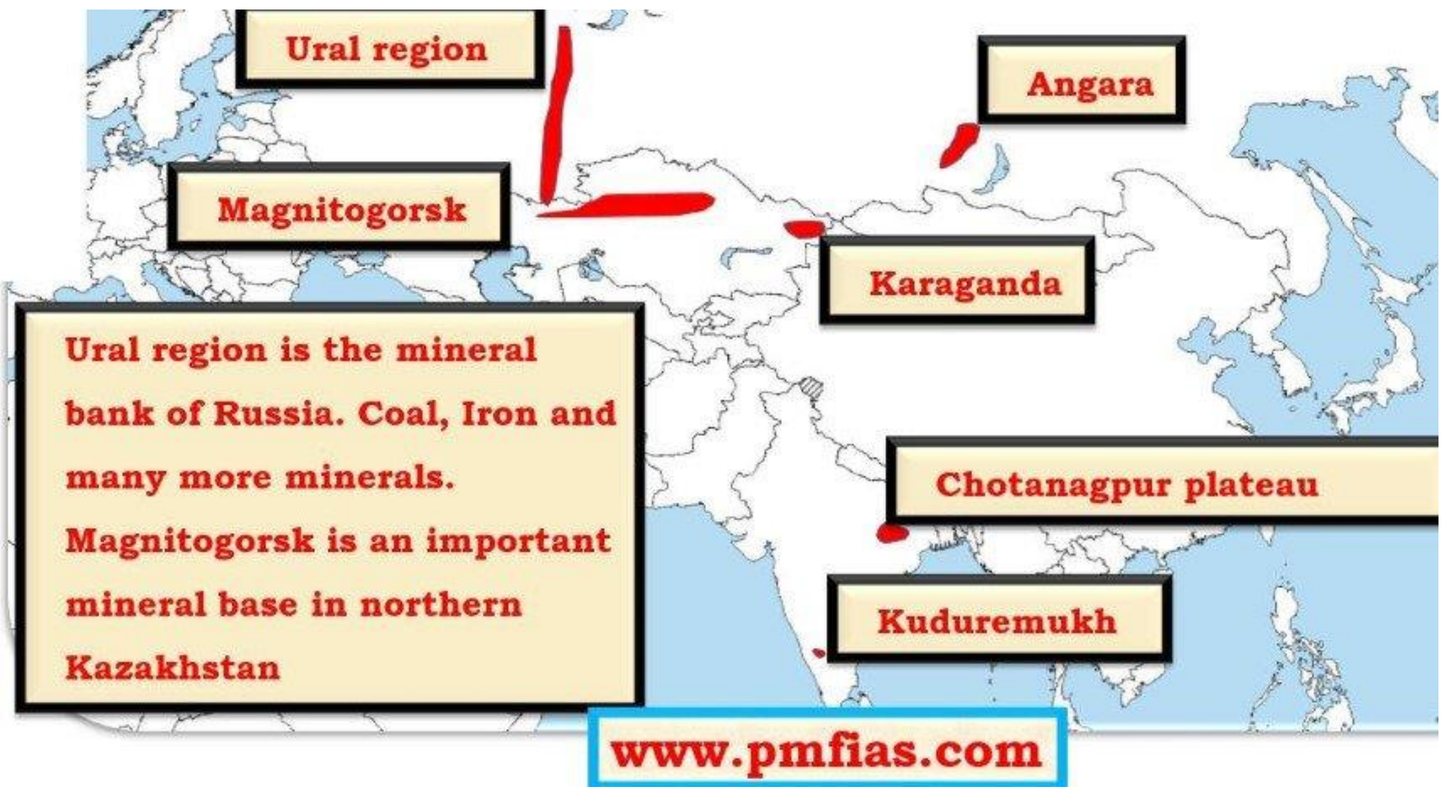
Iron Ore in Europe – Ruhr, South Whales, Krivoy Rog, Bilbao, Lorraine



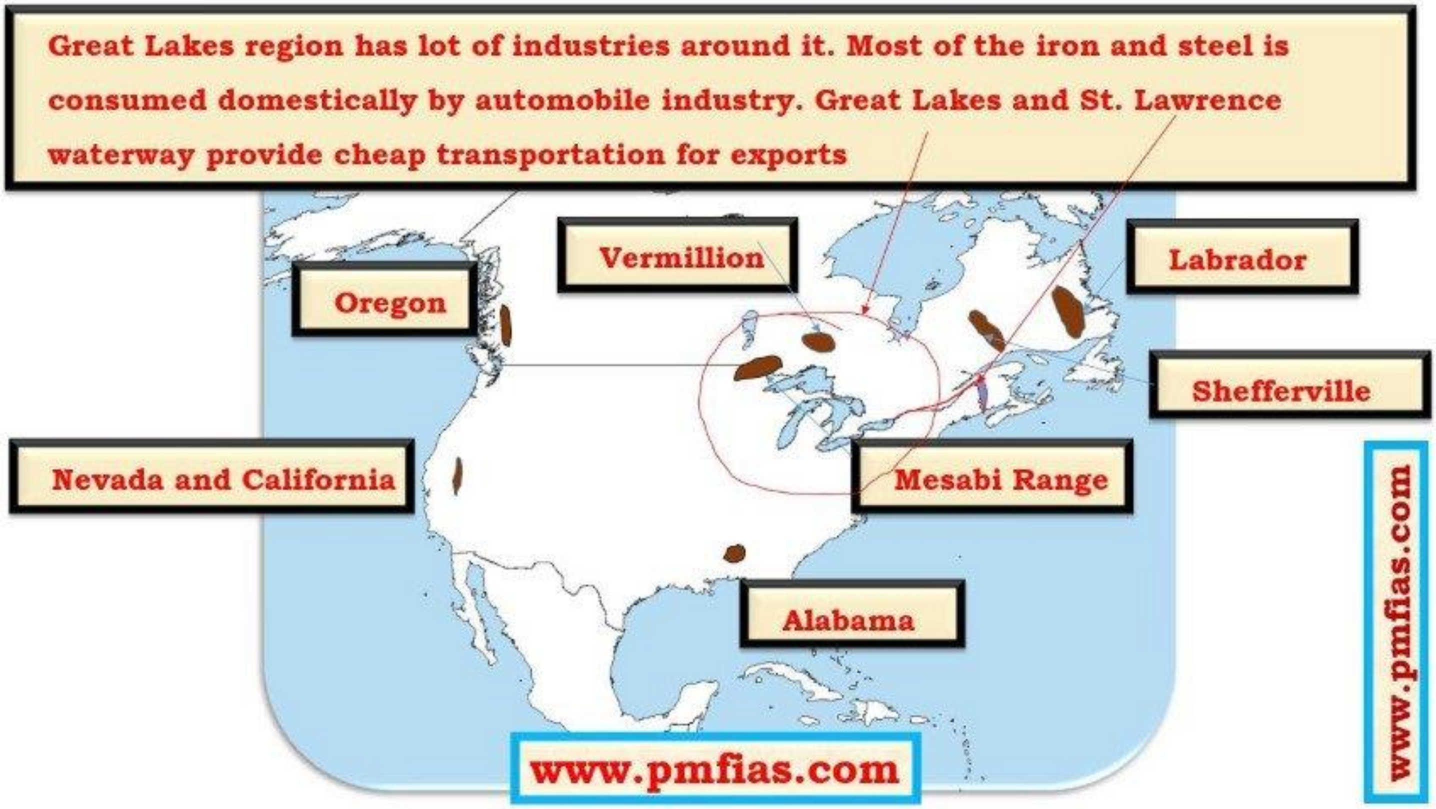
Iron ore Africa Transvaal, Liberia



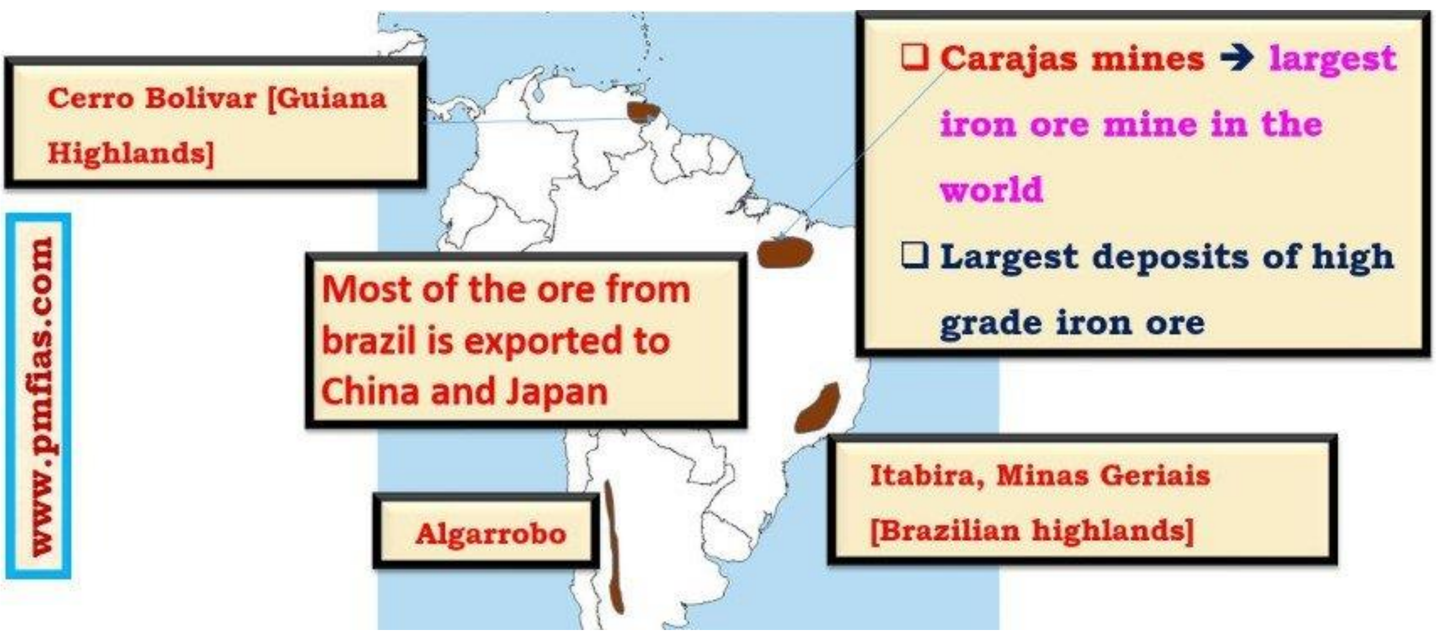
Iron ore in Russia, Kazakhstan – Ural region, Magnitogorsk



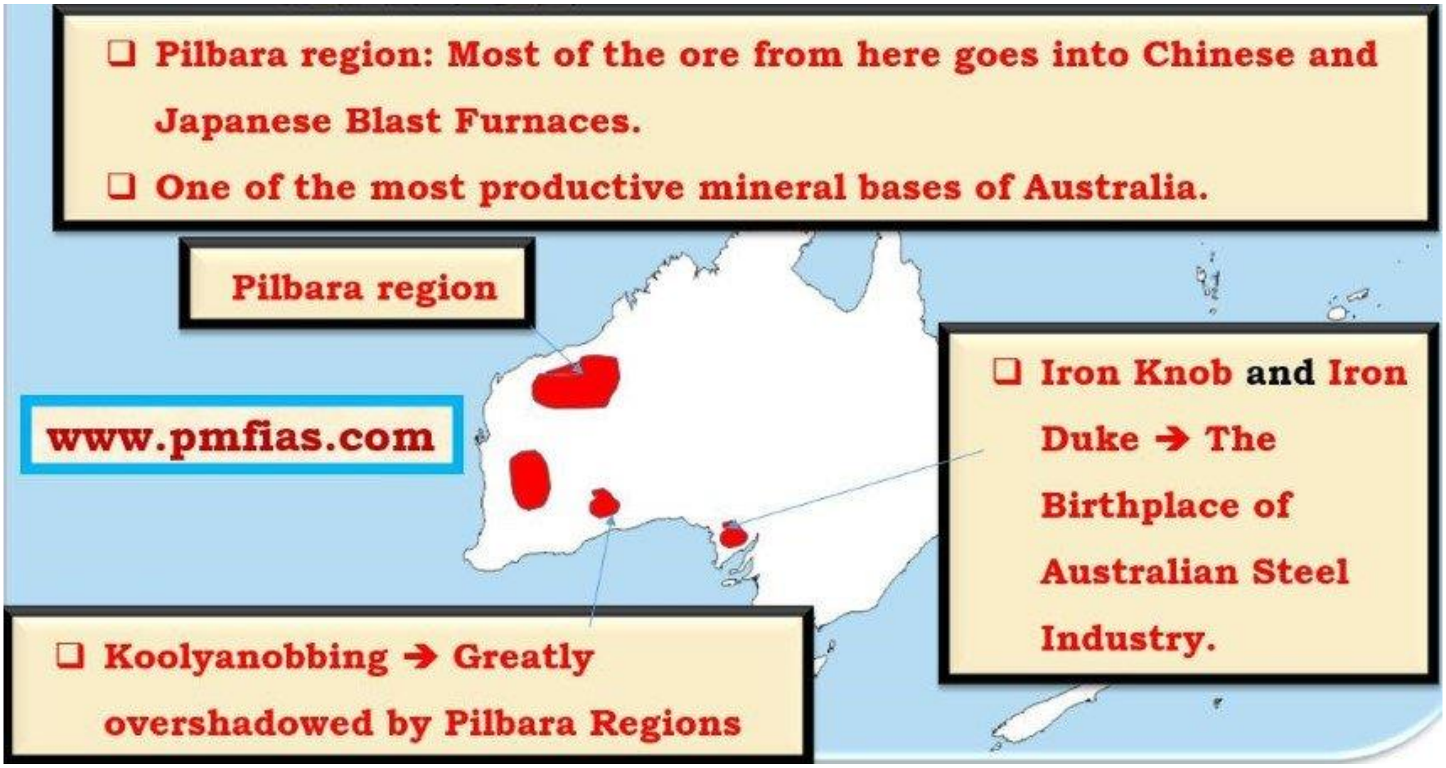
Iron Ore in North America – Great Lakes [Mesabi Region], Labrador



Iron Ore in South America – Carajas, Itabira, Minas Geriais



Iron Ore in Australia – Pilbara Region, Koolyanobbing, Iron Duke, Iron Knob



Types of Iron Ore – Haematite, Magnetite, Limonite & Siderite. Distribution of Iron Ore in India – Iron ore in Orissa, Jharkhand, Chhattisgarh, Karnataka & other states.

Previous post: Iron Ore Distribution across the World.

Types of Iron Ore

- Haematite, Magnetite, Limonite & Siderite.

Haematite

- Reddish; **best quality**; 70 per cent metallic content.
- Found in **Dharwad and Cuddapah rock systems** of the peninsular India.
- 80 per cent of haematite reserves are in Odisha, Jharkhand, Chhattisgarh and Andhra Pradesh.
- In the western section, Karnataka, Maharashtra and Goa has this kind of ore.

Magnetite

- Black ore; 60 to 70 per cent metallic content.
- Dharward and Cuddapah systems.
- **Magnetic quality.**
- Karnataka, Andhra Pradesh, Rajasthan, Tamil Nadu and Kerala.

Limonite

- Inferior ores; yellowish in colour; 40 to 60 per cent iron metal.
- Damuda series in Raniganj coal field, Garhwal in Uttarakhand, Mirzapur in Uttar Pradesh and Kangra valley of Himachal Pradesh.
- Advantage == open cast mines == **easy and cheap mining**.

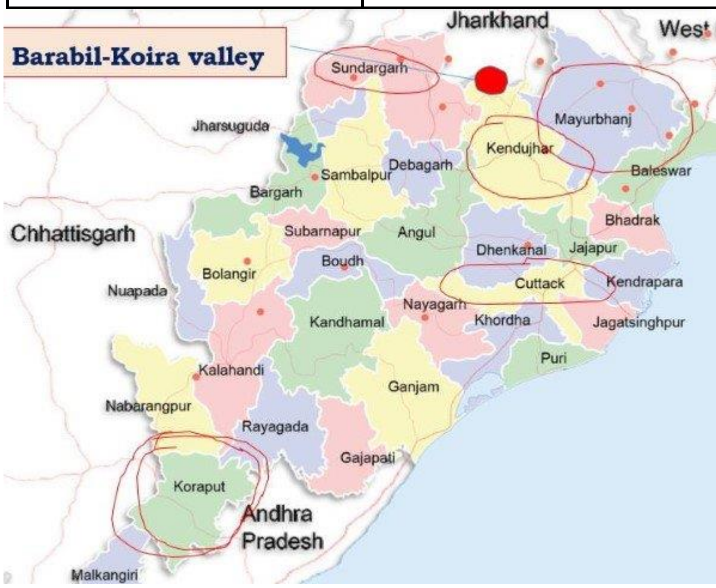
Siderite

- 'Iron carbonate'; inferior quality; less than 40 per cent iron.
- Contains many impurities {previous post}; mining is not economically variable.
- However, it is **self-fluxing** due to presence of lime.

Iron Ore Distribution in India

- **Hematite** and **magnetite** are the two most important iron ores in India

Exact Numbers not important. Remember 1st and 2nd position.	**Haematite**	**Magnetite**
Reserves	~18,000 million tonnes Which type of iron ore is abundant in India? Haematite Magnetite	~10,500 million tonnes
Major states	Odisha 33% Jharkhand 26% Chhattisgarh 18% Rest in Andhra Pradesh, Assam, Bihar, Maharashtra, MP, Rajasthan, UP	Karnataka 73% Andhra Pradesh 14% Rajasthan 5% TN 4.9% Rest in Assam, Bihar, Goa, Jharkhand, Kerala, MH, Meghalaya and Nagaland



Q1. Statements

1) Karnataka has more than half of the reserves of magnetite ore in India.
2) Jharkhand has the highest reserves of haematite ore in India.

Which of the above are true?

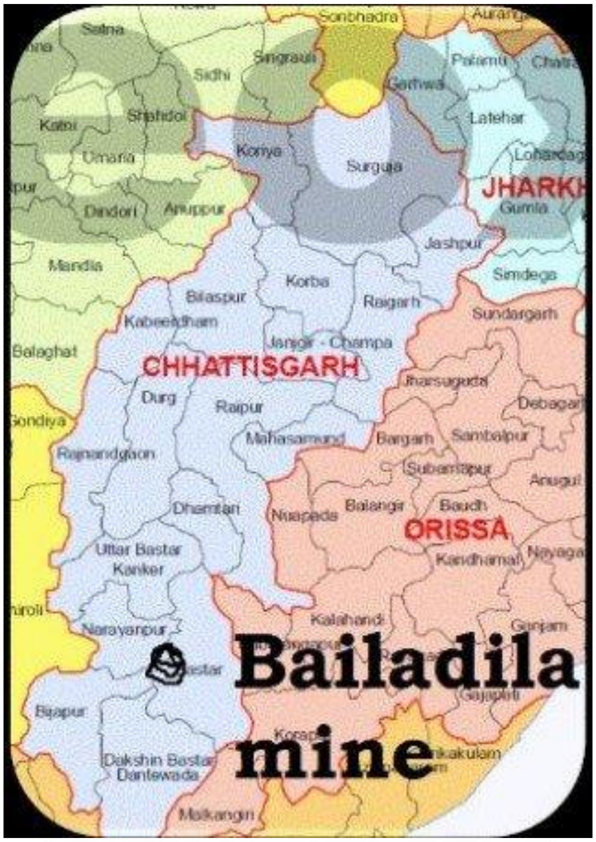
a) Both
b) 1 only
c) 2 only
d) None

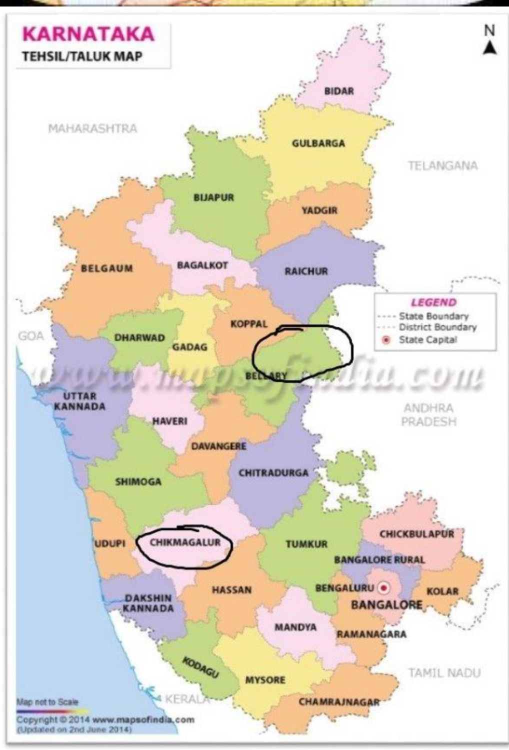
Iron Ore in Orissa

- The ores are rich in haematites.
- India's richest haematite deposits are located in **Barabil-Koira valley**.
- Others: Sundargarh, Mayurbhanj, Cuttack, Sambalpur, Keonjhar and Koraput districts.

Iron Ore in Chhattisgarh

- **Bailadila mine** is the largest mechanised mine in Asia [Ore benefication only done here]
- A 270 km long slurry (a semi-liquid mixture) pipeline from the Bailadila to Vizag plant transports the ore slurry.
- Smelting is done in Vizag [Vishakhapatnam] iron and steel factory.
- Bailadila's high grade ore is exported through Vishakhapatnam to **Japan** [No iron ore in Japan. But market is huge due to **automobile industry**] and other countries.
- The **Dalli-Rajhara** range is 32 km long [ferrous content 68-69 per cent] range with significant reserves.





Iron Ore in Jharkhand

- 25 per cent of reserves.
- First mine in Singhbhum district in 1904.
- Iron ore of here is of **highest quality** and will last for **hundreds of years.**
- **Noamandi mines** in Singhbhum are the richest.
- Magnetite ores occur near Daltenganj in Palamu district.

Iron Ore in Karnataka

- Iron ores are widely distributed.
- High grade ore deposits are those of **Kemmangundi in Bababudan hills of Chikmagalur district** and **Sandur and Hospet in Bellary** district. [Lot of Mining Mafia].
- Most of the ores are **high grade** haematite and magnetite.

Iron ore in other states

- Andhra Pradesh (1.02%): Kurnool, Guntur, Cuddapah, Ananthapur, Nellore.
- Maharashtra (0.88%): Chandrapur, Ratnagiri and Sindhudurg.
- Madhya Pradesh (0.66%).
- Tamilnadu: Salem, Tiruchirapalli, Coimbatore, Madurai etc.
- Rajasthan: Jaipur, Alwar, Sikar, Bundi, Bhilwara.
- Uttar Pradesh: Mirzapur.
- Uttaranchal: Garhwal, Almora, Nainital.
- Himachal Pradesh: Kangra and Mandi.
- Haryana: Mahendragarh.
- West Bengal: Burdwan, Birbhum, Darjeeling.
- Jammu and Kashmir: Udhampur and Jammu.
- Gujarat: Bhavnagar, Junagadh, Vadodara.
- Kerala: Kozhikode.

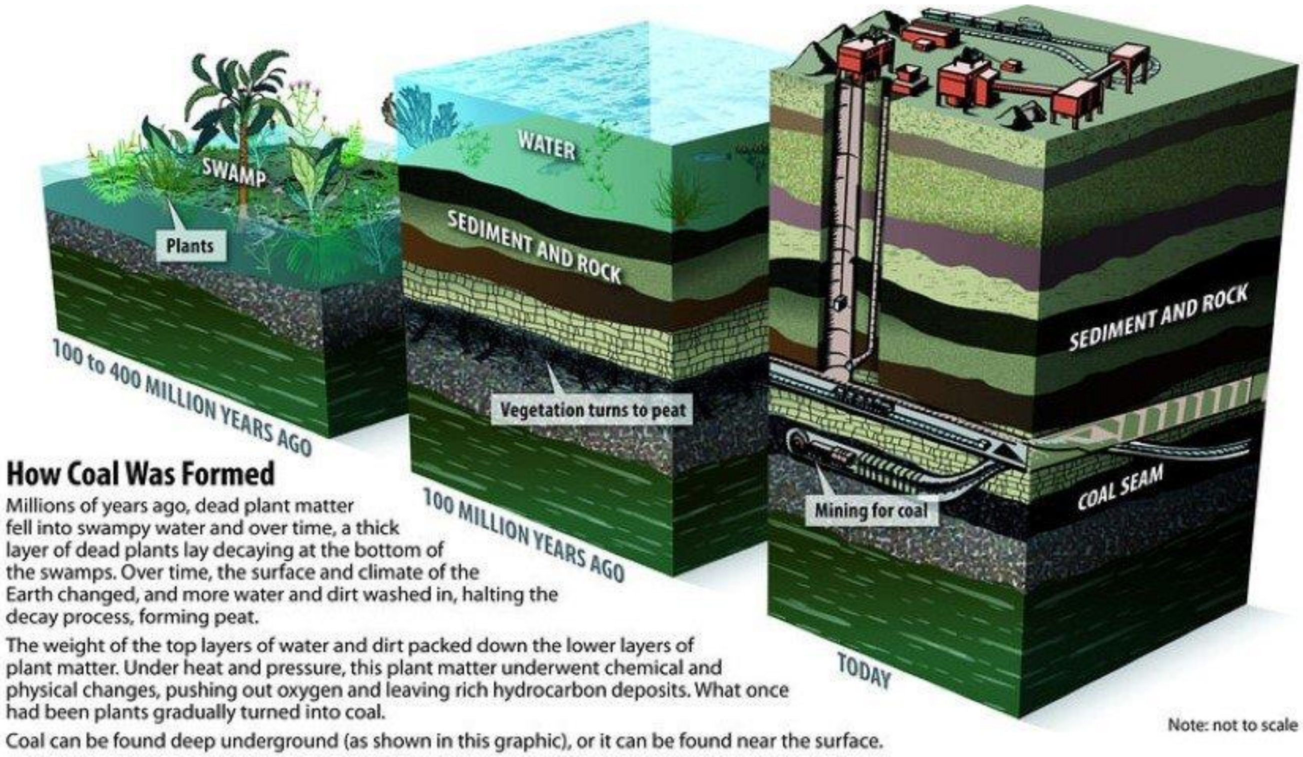
Coal – Formation of Coal – Types of Coal – Peat, Lignite, Bituminous Coal & Anthracite Coal. Carbon content in different types of coal. Importance of each type.

Coa

- Also called **black gold**.
- Found in sedimentary strata [layers of soil].
- Contains **carbon, volatile matter, moisture** and **ash** [in some cases **Sulphur** and **phosphorous**]

- Mostly used for power generation and metallurgy.
- Coal reserves are six times greater than oil and petroleum reserves.

Formation of Coal



- Most of the world's coal was formed in **Carboniferous age [350 million years ago][Best quality coal].**

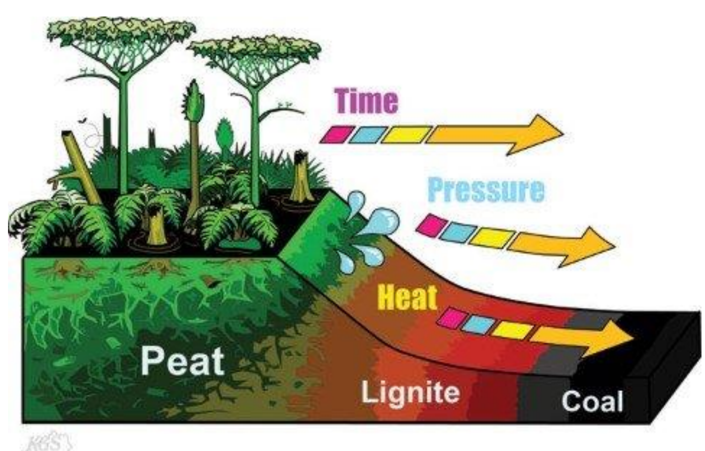
Carboniferous age: In terms of absolute time, the Carboniferous Period began approximately 358.9 million years ago and ended 298.9 million years ago. Its duration is approximately 60 million years.

The name Carboniferous refers to coal-bearing strata.

*Amount of **oxygen, nitrogen and moisture content decreases** with time while the **proportion of carbon increases** [The quantity of carbon doesn't increase, only its proportion increases due to the loss of other elements].*

Capacity of coal to give energy depends upon the percentage or carbon content [Older the coal, much more is its carbon content].

*Percentage of carbon in coal depends upon the duration and intensity of heat and pressure on wood. [carbon content also depends on depth of formation. **More depth == more pressure and heat == better carbon content**].*



- Coal formed millions of years ago when the earth was covered with huge swampy [marshy] forests where plants - giant ferns and mosses - grew.
- As the plants grew, some died and fell into the swamp waters. New plants grew up to

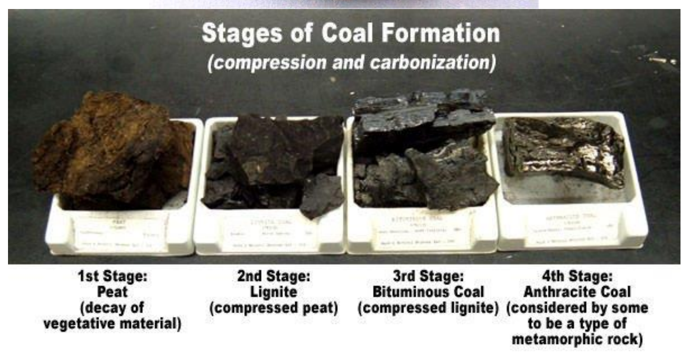
take their places and when these died still more grew.

- In time, there was thick layer of dead plants rotting in the swamp. The surface of the earth changed and water and dirt washed in, **stopping the decaying process**.
- More plants grew up, but they too died and fell, forming separate layers. After millions of years many layers had formed, one on top of the other.
- The weight of the top layers and the water and dirt packed down the lower layers of plant matter.
- Heat and pressure produced chemical and physical changes in the plant layers which **forced out oxygen and left rich carbon deposits**. In time, material that had been plants became coal.
- Coals are classified into three main ranks, or types: **lignite, bituminous coal, and anthracite.**
- These classifications are based on the **amount of carbon, oxygen, and hydrogen present in the coal.**
- Coals other constituents include **hydrogen, oxygen, nitrogen, ash, and sulfur.**
- Some of the undesirable chemical constituents include **chlorine and sodium**.
- In the process of transformation (coalification), ***peat is altered to lignite, lignite is altered to sub-bituminous, sub-bituminous coal is altered to bituminous coal, and bituminous coal is altered to anthracite.***

Peat, Lignite, Bituminous & Anthracite Coal

Peat

- First stage of transformation.
- Contains **less than 40 to 55 per cent carbon == more impurities.**
- Contains sufficient volatile matter and **lot of moisture** [more smoke and more pollution].
- Left to itself, it burns like **wood**, gives less heat, emits more smoke and leaves a **lot of ash.**



Lignite

- **Brown coal.**
- Lower grade coal.
- **40 to 55 per cent carbon.**
- Intermediate stage.
- Dark to black brown.
- Moisture content is high (over 35 per cent).
- It undergoes **SPONTANEOUS COMBUSTION** [Bad. Creates fire accidents in mines]

Bituminous Coal

- Soft coal; most widely available and used coal.
- Derives its name after a liquid called **bitumen.**
- **40 to 80 per cent carbon.**
- Moisture and volatile content (15 to 40 per cent)
- Dense, compact, and is usually of black colour.
- **Does not have traces of original vegetable material.**
- Calorific value is **very high** due to high proportion of carbon and low moisture.
- Used in production of **coke and gas**.

Anthracite Coal

- **Best quality**; hard coal.
- **80 to 95 per cent carbon**.
- Very little volatile matter.
- Negligibly small proportion of moisture.
- Semi-metallic lustre.
- **Ignites slowly** == less loss of heat == highly efficient.
- Ignites slowly and burns with a nice short **blue flame. [Complete combustion == Flame is BLUE == little or no pollutants. Example: LPG]**
- In India, it is found only in Jammu and Kashmir and that too in small quantity.

Distribution of Coal in India – Gondwana Coal: Gondwana Coalfields. Tertiary Coal: Tertiary Coalfields, Lignite, Peat. Coking Coal vs. Non-Coking Coal, Coal Reserves, Coal Production, Imports.

Distribution of Coal in India

- **Gondwana coal fields [250 million years old]**
- **Tertiary coal fields [15 – 60 million years old]**

Gondwana Coal

- Gondwana coal makes up to **98 per cent of the total reserves and 99 per cent of the production of coal in India.** Satpuras, denudation [weathering + erosion] has exposed coal bearing Gondwana strata.
- The carbon content in Gondwana coal **[250 million years old]** is less compared to the Carboniferous coal **[350 million years old][Almost Absent in India]** because of its much younger age.
- Gondwana coal forms India's metallurgical grade as well as superior quality coal.
- The **Damuda series (i.e. Lower Gondwana)** possesses the best worked coalfields accounting for 80 per cent of the total coal production in India. 80 out of 113 Indian coalfields are located in the rock systems of the **Damuda series [**lower Gondwana Age**]**.
- Coking as well as non-coking and bituminous as well as sub-bituminous coal are obtained from Gondwana coal fields.
- **Anthracite** is generally not found in the Gondwana coal fields.
- The volatile compounds and ash (usually 13 - 30 per cent) and doesn't allow Carbon percentage to rise above **55 to 60 per cent.** [It requires few million years more if the quality has to get better. Remember Gondwana coal is 100 million years younger than Carboniferous coal].
- Gondwana coal is free from moisture, but it contains **Sulphur** and **phosphorus.**
- These basins occur in the valleys of certain rivers viz., the Damodar (Jharkhand-West Bengal); the Mahanadi (Chhattisgarh-Odisha); the Son (Madhya Pradesh Jharkhand); the Godavari and the Wardha (Maharashtra-Andhra Pradesh); the Indravati, the Narmada, the Koel, the Panch, the Kanhan and many more.

Distribution of Gondwana Coal in India

- First coal mine was opened in 1774 at **Raniganj in West Bengal.**
- Coal industry was nationalized in 1973-74. [The present government made some serious changes during the last year [2015] by allowing private sector to play a bigger role in coal production].

- India is now the **third largest coal producer** in the world after **China and the USA**.
- Coal industry provides employment to nearly seven lakh persons.
- Gondwana Coalfields == exclusively found in the Peninsular plateau of India

Gondwana Coalfields in Chhattisgarh

Coalfield	Extent
Korba coalfield	Korba district.
Birampur coalfield	Surguja district.
Hasdo-Arand coalfield	
Chirmiri coalfield	
Lakhanpur coalfield	
Jhilmili coalfield	Shandol district & Koriya district
Johilla coalfield	Johilla valley
Sonhat coalfield	Surguja district
Tatapani-Ramkota coalfields	north-eastern part of Surguja district

Gondwana Coalfields in Jharkhand

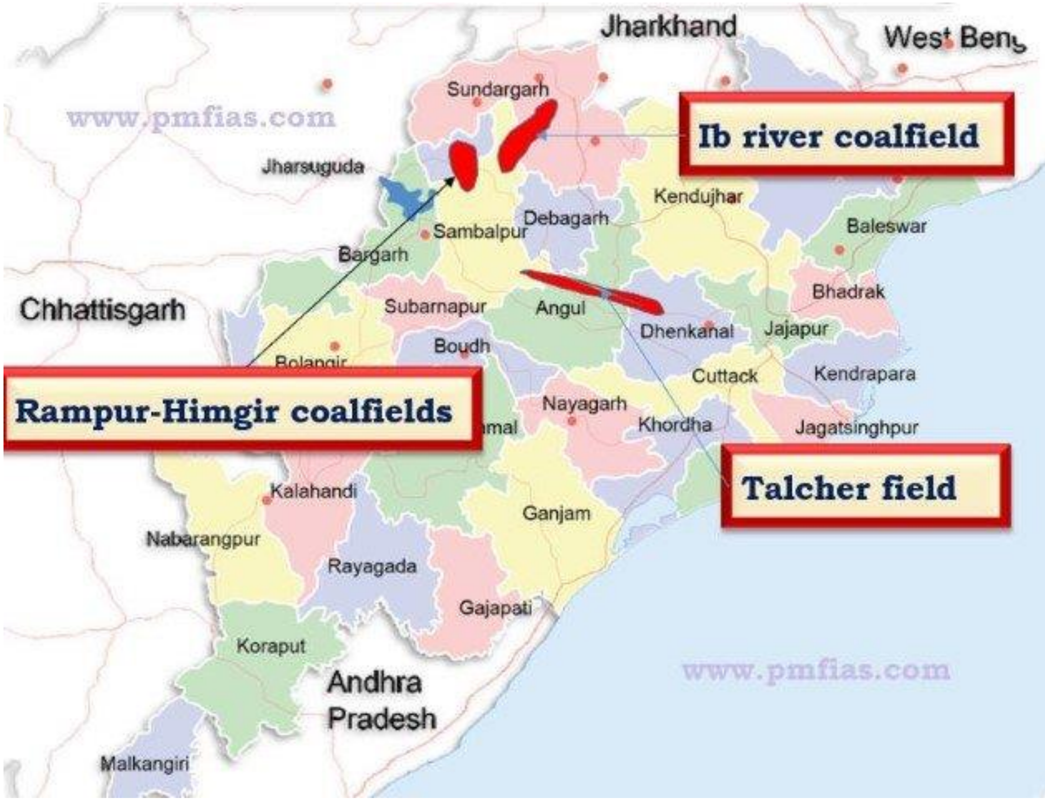
- 1st in reserves [28%].
- 2nd in production [20%].
- Most of the coal fields are located in a narrow belt running in east-west direction.
- Major coalfields are present in Dumka (Santhal Parganas), Hazaribagh, Dhanbad and Palamu.
- **Jharia, Bokaro, Girdih and Karanpura** are the major coal fields

Jharia coalfield	Danbad district	One of the **oldest and the richest coalfields** of India; store house of the best **metallurgical coal [coking coal]**
Jayanti coalfields		inferior quality and has high ash content
Bokaro coalfield West Bokaro [900 m deep] East Bokaro [600 m deep]	Hazaribagh district	It is a long but narrow strip in the catchment area of the **Bokaro river.**
Girdih (Karharbari) coalfield		Gives out of the **finest coking coal** in India for metallurgical purposes.
Karanpura and Ramgarh coalfields		
Auranga coalfield	Palamu district	inferior quality; used in cement furnaces and brick kilns
Hutar coalfield		
Deltenganj coalfield		
Devgarh coalfields		inferior quality
Rajmahal coalfield	Rajmahal hills	inferior quality

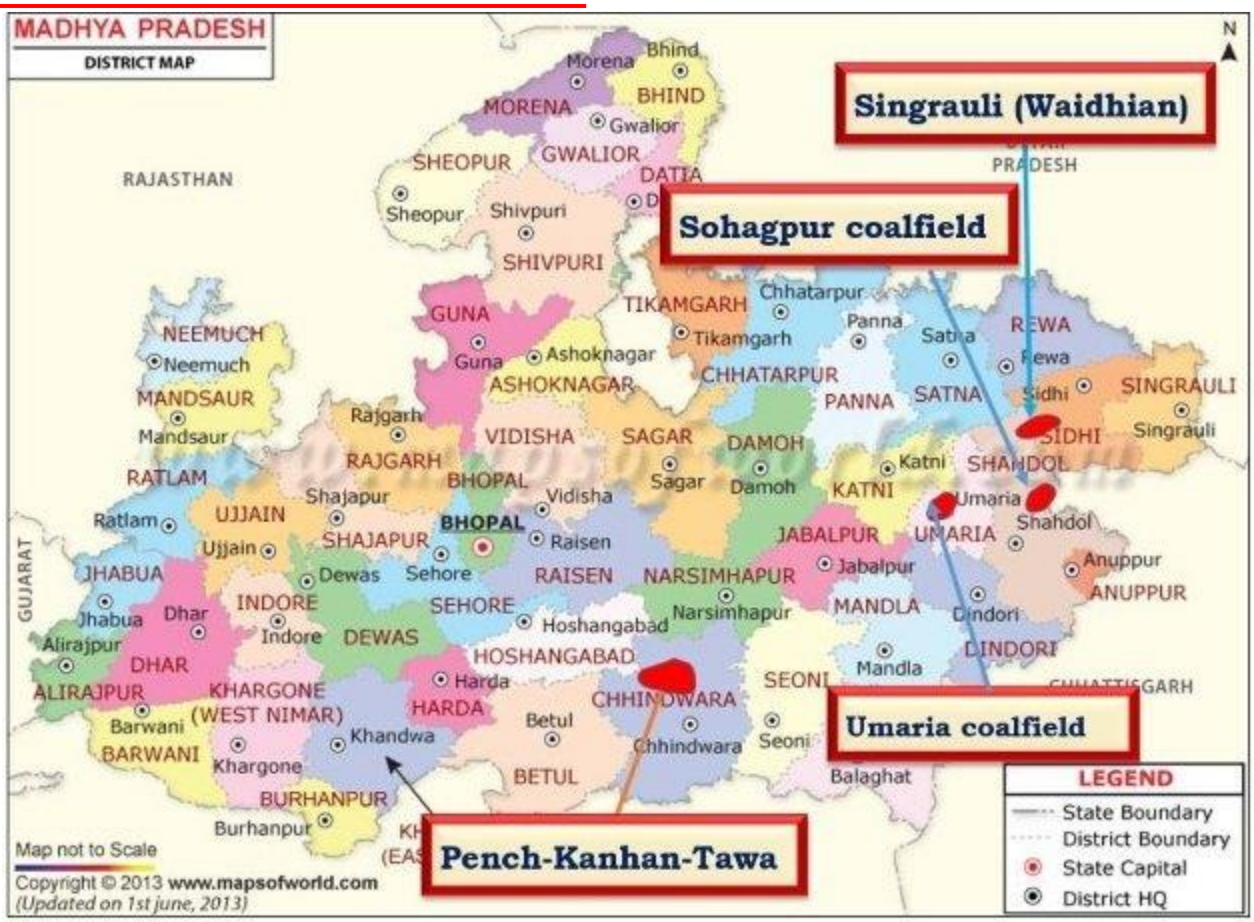
Coalfield locations can be asked in Prelims.

Gondwana Coalfields in Odisha

Talcher field	Talcher town to Rairkhol in Dhenkanal and Sambalpur districts	Ranks **second in reserves** (24,374 million tonnes) after **Raniganj**; Coal from this field is most suitable for steam and gas production. Most of the coal is utilised in **thermal power and fertilizer plants at Talcher.**
Rampur-Himgir coalfields	Sambalpur and Sundargarh	Coal occurs here in middle and lower Barakar seams. inferior quality
Ib river coalfield	Sambalpur and Jharsuguda district	Much of the coal is of inferior quality.

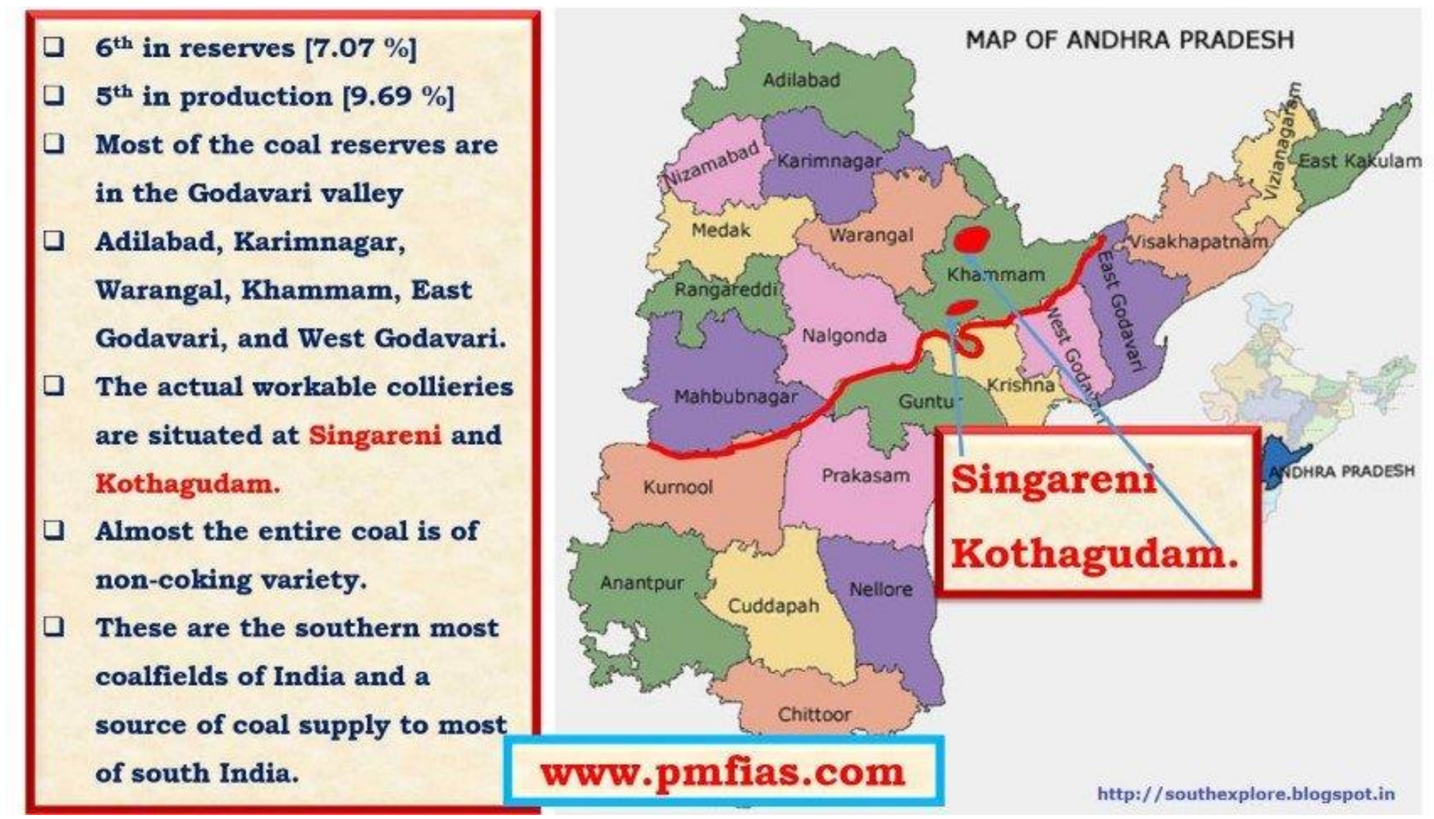


Gondwana Coalfields in Madhya Pradesh



Singrauli (Waidhian) coalfield	Sidhi and Shandol districts	largest coalfield of Madhya Pradesh Jhingurda, Panipahari, Khadia, Purewa and Turra are important coal seams Jhingurda with a total thickness of 131 m is the richest coal seam of the country. thermal power plants at Singrauli and Obra
Pench-Kanhan-Tawa	Chhindwara district	Ghoravari seam in Kanhan field is 4.6 m thick and contains coking coal
Sohagpur coalfield	Shandol district	
Umaria coalfield	Umaria district	inferior quality with high percentage of moisture and ash.

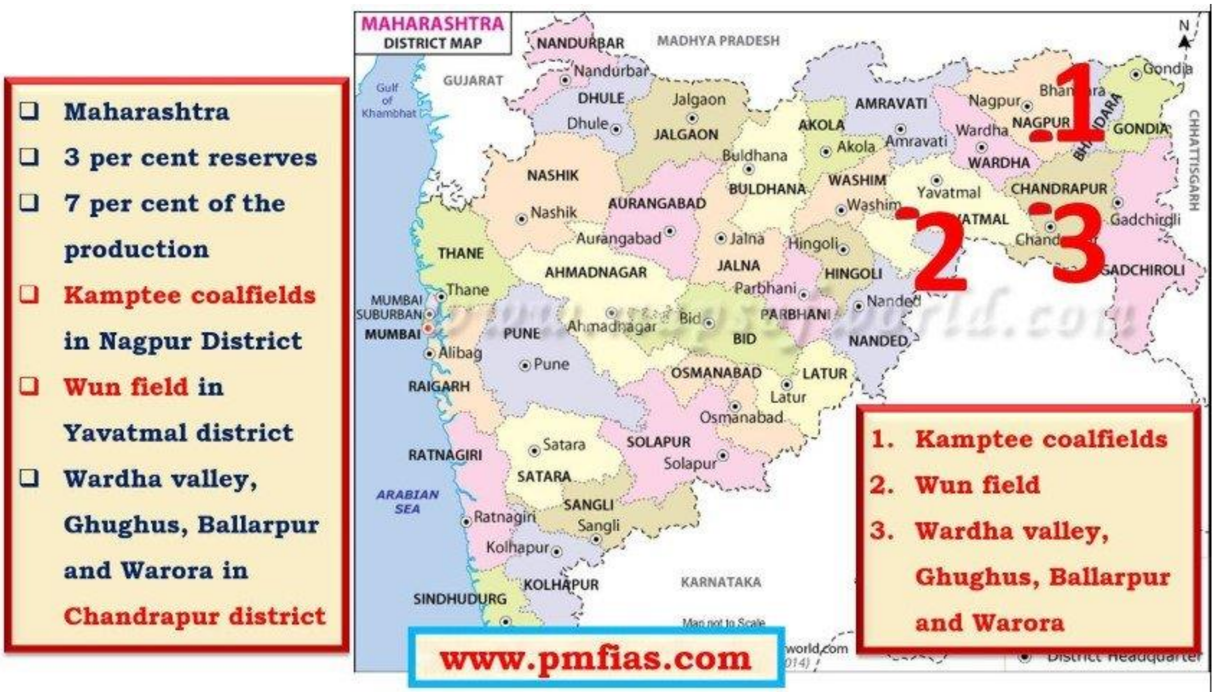
Gondwana Coalfields in Andhra Pradesh



- 6th in reserves [7.07 %].
- 5th in production [9.69 %].
- Most of the coal reserves are in the **Godavari valley.**
- Adilabad, Karimnagar, Warangal, Khammam, East Godavari, and West Godavari.
- The actual workable collieries are situated at **Singareni and Kothagudam.**
- Almost the entire coal is of **non-coking variety.**
- These are the southern most coalfields of India and a **source of coal supply to most of south India.**

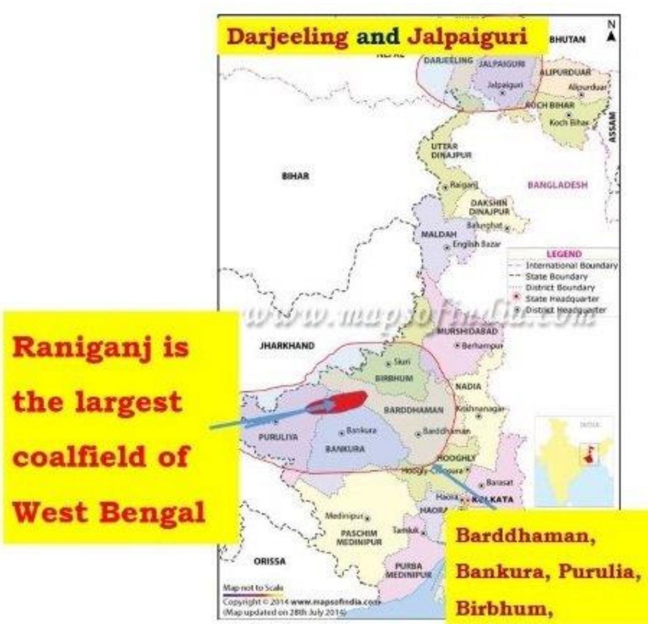
Gondwana Coalfields in Maharashtra

- 3 per cent reserves.
- 7 per cent of the production.



Gondwana Coalfields in West Bengal

- 4 % of India's coal.
- 11 % of the coal reserves.
- **Darjeeling** and **Jalpaiguri** are the chief producing districts.
- **RANIGANJ** is the largest coalfield of West Bengal.
- Raniganj == Barddhaman, Bankura and Purulia districts; Small part of this field is in Jharkhand state.
- The coal here is non-coking steam coal.
- Dalingkot coalfield == Darjeeling district.



Gondwana Coalfields in Uttar Pradesh

- Do not possess coal reserves.
- A small portion of the Singrauli field of Madhya Pradesh falls within Mirzapur district.
- A high grade coal seam, about 1 to 1.5 m thick occurs near Kotah.

Tertiary Coal

- Tertiary coal 15 to 60 million years old. Carbon content is very low.
- Mainly confined to the extra-Peninsula [Jammu and Kashmir, Himachal Pradesh, Assam, Arunachal Pradesh etc.]
- Coal generally has **low carbon** and **high percentage of moisture** and **Sulphur**.[It takes few hundred million years for the carbon content to improve].
- Important areas of Tertiary coal include parts of Assam, Meghalaya, Arunachal Pradesh, Nagaland, Himalayan foothills of Darjeeling in West Bengal, Jammu and Kashmir, Uttar Pradesh, Rajasthan, Kerala,
- Tamil Nadu and the union territory of Pondicherry also bear tertiary coal reserves [exceptions].

Tertiary Coalfields in Assam

- Makum, Nazira, Mikir Hills, Dilli-Jeypore and Lakhuni.
- **Makum coalfield** in Sibsagar district is the most developed field.
- Assam coals contain very **low ash and high coking qualities** but the **sulphur content is high**, as a result of which this coal is not suitable for metallurgical purposes.
- But these coals are best suited for **hydrogenation process** and are used for **making liquid fuels.**

Tertiary Coalfields in Arunachal Pradesh

- Upper Assam Coal belt extends eastwards as Namchick-Namrup coalfield.
- High in volatiles and in sulphur.

Tertiary Coalfields in Meghalaya

- Garo, Khasi and Jaintia hills.
- Darrangiri field == Garo hills.
- Siju, Cherrapunji, Liotryngew, Maolong and Langrin coalfields == Khasi and Jaintia hills.

Tertiary Coalfields in Jammu and Kashmir, Himachal Pradesh

- Kalakot and surrounding regions in Jammu, south of Pirpanjal.
- Himachal Pradesh == Chamba district.

Tertiary Coal – Lignite

- Tamil Nadu, Gujarat, Jammu and Kashmir, Kerala, Rajasthan, West Bengal and Puducherry.
- Tamil Nadu excels all other states regarding reserves and production of lignite.

Lignite in Tamil Nadu

- **90 per cent** of the reserves.
- 57 per cent of the production.
- **Neyveli Lignite fields** of Cuddalore district.
- These are the largest deposits of lignite in south - east Asia.
- Neyveli mines suffer from the artesian structure [mining goes deep and deep].
- Mining in Lignite coalfields is risky due to **SPONTANEOUS COMBUSTION** of lignite.

Lignite in Gujarat and Rajasthan

- Kachchh district and Dharuch district; poor quality.
- Rajasthan == Palana in Bikaner district; The 250 MW thermal plant at **Bikaner** wholly depends upon lignite as the basic fuel.

Tertiary Coal – Peat

- Confined to a few areas only.
- Occurs in **Nilgiri hills**.
- **Kashmir valley**, peat occurs in the alluvium of the Jhelum.
- In West Bengal peat beds are noted in Kolkata and its suburbs.
- In the Ganga delta, there are layers of peat which are composed of forest and rice plants.

Problems of Coal Mining in India

- The distribution of coal is uneven.
- High ash content and low caloric value.
- Large percentage of coal is taken out from underground mines. [Very few open cast mines]
- Heavy losses due to fires in the mines.
- Pilferage at several stages also adds to losses – bad transportation infrastructure.
- Serious problem of environmental pollution. High ash, moisture == more smoke.
- Safety measures against environmental pollution are very costly. Clean coal technology == Complex technology.
- Misuse of good quality coal for burning into transport and industries.
- Short life of metallurgical coal.
- Selective mining leading to large scale wastage of raw coal
- Unscientific method of extraction of coal.

Measures to be taken

- Coking coal should be used for metallurgical industry only.
- Low grade coal should be washed and blended with superior quality coal in requisite proportion and used in industries. [Clean Coal Technology]
- Selective mining should be discouraged and all possible coal from the mines should be taken out.
- New reserves should be discovered and new techniques should be adopted.
- Alternative energy sources should be encouraged.

Coking Coal vs. Non-Coking Coal

Coking Coal or Metallurgical Coal	Thermal Coal or Non-Coking Coal or Steaming coal
High carbon content, less moisture, less sulphur, less ash. **Sulphur** is very bad for iron and steel industry.	Sulphur content is high and hence cannot be used in iron and steel industry.
Used to create **coke.** Coke is produced by heating bituminous coal without air to extremely high temperatures. Coking == flushing out impurities and improving the concentration of carbon.	Creating coke using this coal is not economical. Moreover traces of sulphur will remain even after coking.
Coking coal is an essential ingredient in steel production.	Thermal coal is used to **generate power.**
Major producers: Australia, Canada, United States. Major exporters: Australia, Canada, United States. China imports huge amount of coking coal from Australia. India also imports coking coal.	Major producers: China, Australia, USA, Russia. Major exporters: Australia, South Africa.

Coal Reserves in India by State

Name of the state	Reserves in billion tonne	% of total reserves
JHARKHAND	80.71	26.76
ODISHA	75.07	24.89
CHATTISHGARH	52.53	17.42
WEST BENGAL	31.31	10.38
MADHYA PRADESH	25.67	8.51
ANDHRA PRADESH	22.48	7.45
MAHARASTRA	10.98	3.64
OTHERS	2.81	0.95

Coal Production in India by State

- All data from 2013-2014. For latest data you must follow newspapers or Reports published by Ministry of Coal.
- Remember top 3 positions in all data below.

Coking Coal Production by State

1) **Jharkhand** [More than 90% of India's Coking coal comes from Jharkhand]
2) West Bengal
3) Madhya Pradesh

Non Coking Coal Production By State

1) **Chhattisgarh**
2) **Odisha**

3) Madhya Pradesh
4) Jharkhand
5) Andhra Pradesh

Total Coal Production By State

1) Chhattisgarh
2) Jharkhand
3) Odisha
4) Madhya Pradesh
5) Andhra Pradesh

Statement 4: Coal Production in India by State

States	Coal Production (2013-14) [MT]		
	Coking	Non Coking	Total
Andhra Pradesh		50.469	50.469
Arunachal Pradesh		0	0
Assam		0.664	0.664
Chhattisgarh	0.125	126.970	127.095
Jammu & Kashmir		0.019	0.019
Jharkhand	55.088	58.006	113.014
Madhya Pradesh	0.249	75.341	75.59
Maharashtra		37.223	37.223
Meghalaya		5.732	5.732
Odisha		112.917	112.917
Uttar Pradesh		14.721	14.721
West Bengal	1.356	26.886	28.242
Total Public	49.503	478.578	528.081
Total Private	7.315	30.370	37.685
All India	**56.818**	**508.948**	**565.766**

India's Coal Imports and Exports

Statement 13: Import of Coal to India in 2013-14

Type of Coal	Quantity [MT]	Value [Rs. Million]
Coking	37.191	351926
Non-Coking	131.248	581003
Total	**168.439**	**932929**

Statement 14: Source Country-Wise Import of Coal to India during 2013-14

Country	Quantity [MT]	% Share
Indonesia	103.068	61.19
Australia	34.774	19.63
South Africa	20.618	11.97
USA	3.651	2.16
Canada	1.247	0.74
Others	5.081	3.01
Total	**168.439**	**98.70**

Statement 19: Export of Coal from India by destination during 2013-14

Country	Quantity [MT]	% Share
Bangladesh PR	1.597	74.17
Nepal	0.376	17.46
Bhutan	0.067	3.11
United Arab Emeritus	0.089	4.13
Others	0.022	1.02
Total	**2.153**	**100**

Statement 15: Source Country-Wise Import of Coking Coal to India during 2013-14

Country	Quantity [MT]	% Share
Australia	30.098	80.92
USA	2.651	7.12
South Africa	0.696	1.87
New Zealand	1.157	3.11
Others	2.589	6.96
Total	**37.191**	**100**

Major Coalfields in India

Major Coalfields in India
Singrauli
Karanpura Bokaro
Jharia
Raniganj
Ib & Talcher
Pench & Kanhan
Singareni - Godavari Velley
Lignite: TN, Gujrat And Rajasthan

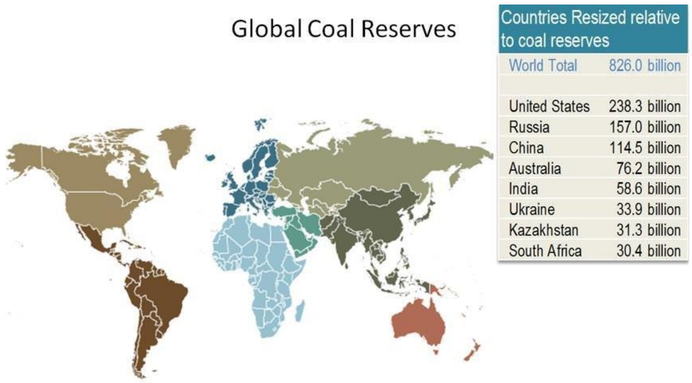
Distribution of Coal across the World – Global Coal Reserves – Top Producers and Consumers of Coal in the World – Distribution of Coal in USA – Distribution of Coal in China.

Distribution of Coal across the World

- Most of the Russia's coal in Siberian Region is untapped.
- Carboniferous coal of Great Lakes and Appalachians region helped USA become a leading industrialized nation.
- Coal reserves in Ruhr and Rhineland region coupled with rich iron deposits have made Germany a leading industrial super power of Europe.
- England too benefited immensely from its coal reserves of South Whales, Yorkshire, Manchester, Liverpool etc. Industrial revolution began here mainly due to rich coal reserves.

- Brazil is a leading coal producer in South America. Most of the coal goes into power generation. Excess production is exported to China.
- Australia is a leading producer of coal. Most of its coal is exported to China, Japan etc. Australia has rick coking coal deposits. India imports coking coal mainly from Australia.
- China's coal is of poor quality. It imports metallurgical grade coal from Australia.
- South Africa is the only region in Africa with significant amount of coal reserves.

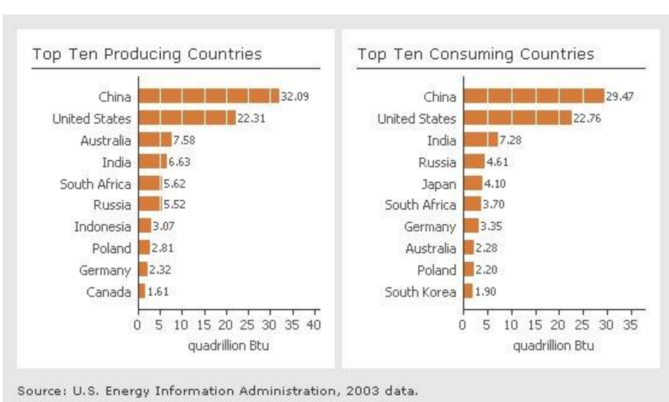
Global Coal Reserves



Distribution of Coal in USA

- World's second biggest coal producing country.
- World's second biggest coal consumer [China first].
- 37% of the country's electricity generation come from coal.
- Coal mining occurs in 25 states of which Wyoming, West Virginia, Kentucky, Pennsylvania and Texas are the biggest coal producers.
- The North Antelope **ROCHELLE COAL MINE** located in the Powder River Basin of Wyoming is the **world's biggest coal mine**
- Allegheny Mountains and Appalachian Mountains have enormous coal deposits.
- Most coal now produced in the United States is mined in western surface mines, especially in Wyoming's Powder River Basin.

Top Producers and Consumers of Coal in the World



Distribution of Coal in China

- World's third biggest coal reserves.
- Largest producer and consumer of coal in the world.
- Largest user of coal-derived electricity [68.7%].
- Industry hugely dependent on Coal.
- Photochemical smog == Intensifying environmental concerns all over China due to coal burning.

Formation of Petroleum and Mineral Oil, Distribution of Petroleum and Mineral Oil in India, On-shore and Off-Shore Oil Production in India.

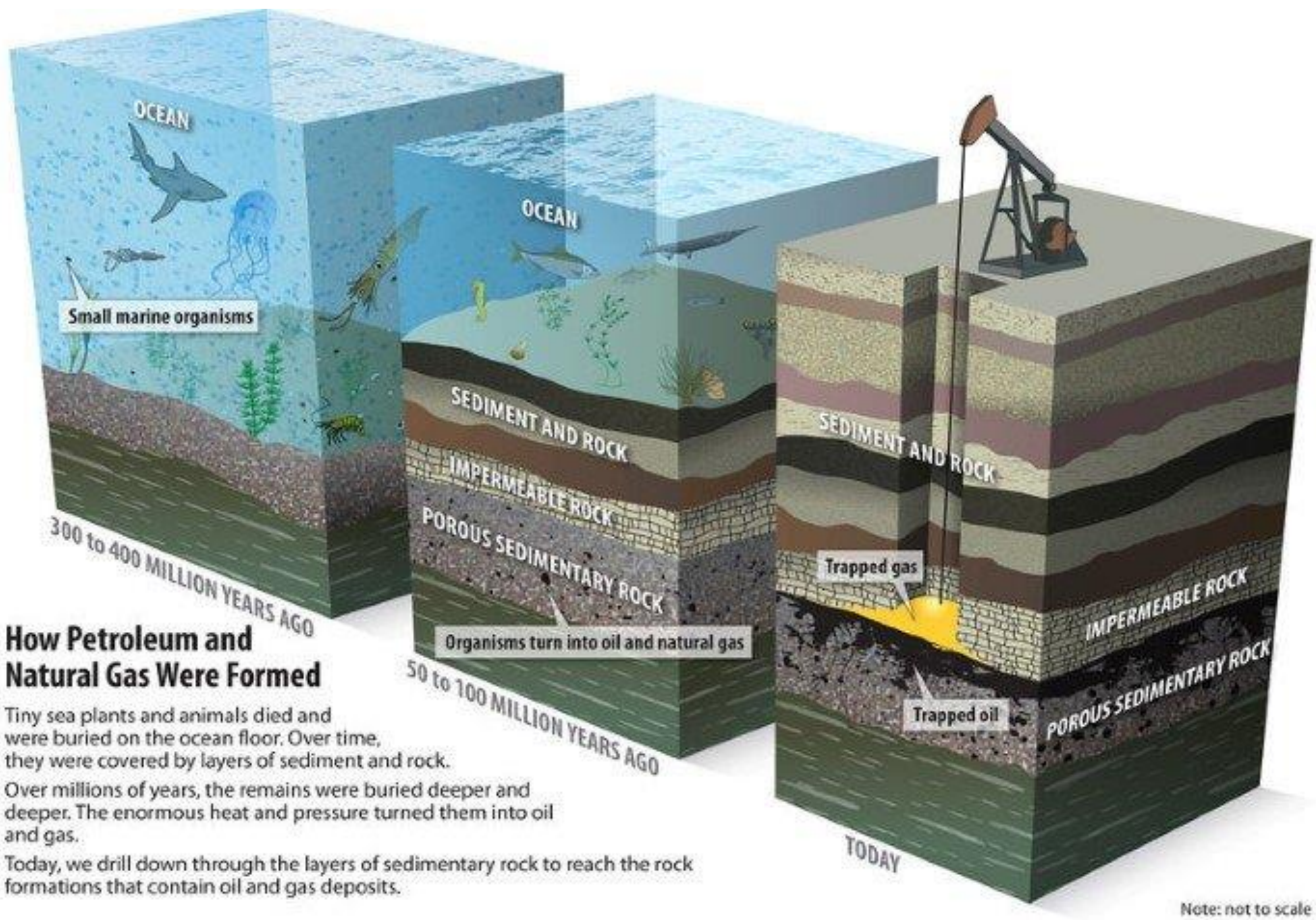
Petroleum and Mineral Oil

- Petra == rock; Oleum == oil.
- Petroleum or Mineral oil is obtained from **sedimentary rocks** of the earth.
- Petroleum fuels on burning gives little smoke and leaves no ash. So they are better than coal.

Constituents of Petroleum and Mineral Oil

- 90 to 95 per cent Hydrocarbons.
- 5 – 10% organic compounds containing **oxygen, nitrogen, sulphur** and traces of organometallic compounds.

Formation of Petroleum and Mineral Oil



- All sedimentary rocks do not contain oil.
- An oil reservoir must have three prerequisite conditions.

1. **Porosity [tiny gaps in soil]** so as to accommodate sufficiently large amounts of oil;
2. **permeability** [allowing liquids or gases to pass through it.] to discharge oil and/or gas when well has been drilled;
3. the porous sandstone beds or fissured limestone containing oil should be **capped below by impervious beds** [not allowing fluid to pass through].

- Most of the oil gets collected in the **anticlines or fault traps**.
- Oil on a commercial scale is usually found in **crests of anticlines** [where the sedimentary rock strata are inclined and folded].

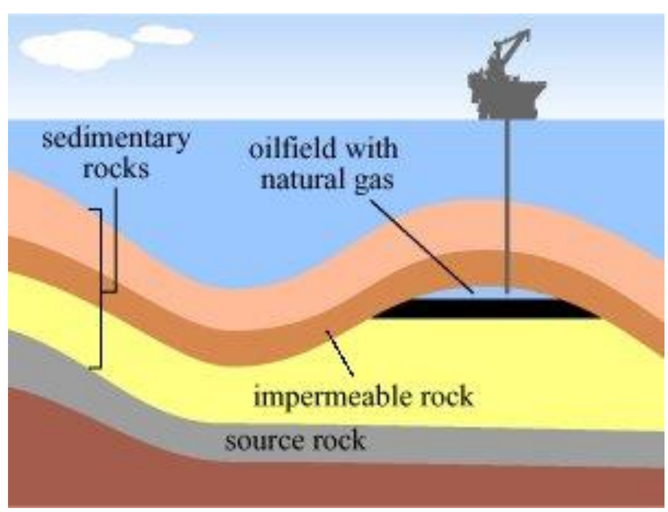
Distribution of Petroleum and Mineral Oil in India

- Process began in tertiary period [3 million years ago].

- Most of the oil reserves in India are associated with **anticlines and fault traps** in the sedimentary rock formations of tertiary times.
- In **tertiary period, aquatic life was abundant** in various forms, especially the minor microscopic forms of flora and fauna.
- Conditions for oil formation were favourable especially in the lower and middle Tertiary period.
- Dense forests and sea organisms flourished in the **gulfs, estuaries, deltas** and the land surrounding them during this period.

Extent of Oil Bearing Strata in India

- 14.1 lakh sq km or 42 per cent of India covered with sedimentary rocks.
- 10 lakh sq km form marine basins of Mesozoic and Tertiary times.
- Total continental shelf of probable oil bearing rocks amounts to **3.2 lakh sq km.**
- The total sedimentary area including both on shore and offshore comprises 27 basins.
- **Mumbai High**, the **Khambhat Gulf** and the **Assam** are the most productive areas.



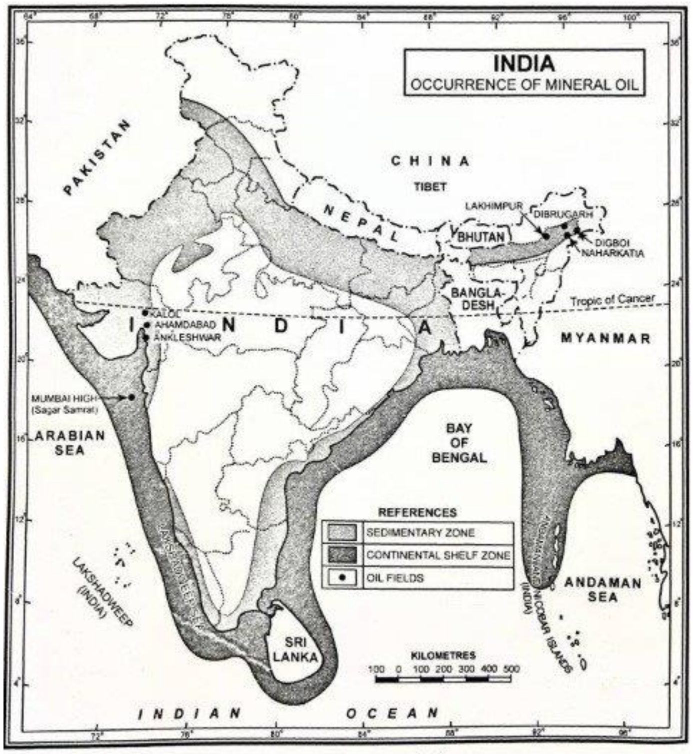


FIG. 24.4. India : Mineral Oil

On-shore Oil Production In India

- **Brahmaputra valley of north-east India.**
- **Barmer area of Rajasthan.**
- **Gujarat coast in western India.**
- **Cauvery on-shore basin in Tamil Nadu.**
- **Andhra Pradesh has both on-shore and offshore oil reserves.**

Assam Oilfields

- Oldest oil producing state in India
- The main oil bearing strata extend for a distance of 320 km in upper Assam along the Brahmaputra valley.
- Oilfields of Assam are relatively **inaccessible** and are **distantly located** from the main consuming areas.
- Oil from Assam is therefore, refined mostly in the refineries located at **Digboi, Guwahati, Bongaigaon, Barauni** and **Numaligarh.**

The Digboi field	Tipam hills, Dibrugarh district	Oldest oil field of India
The Naharkatiya field	Left bank of Burhi Dihing river	32 km southwest of Digboi Oil from this area is sent to oil refineries at Noonamati in Assam (443 km) and Barauni in Bihar (724 km) through pipeline.
The Moran-Hugrijan field	40 km south-west of Naharkatiya	

Gujarat Oilfields

- Ankleshwar, Khambhat or Lunej, Ahmedabad and Kalol, Nawgam, Kosamba, Kathana, Barkol, Mahesana and Sanand are important oilfields of this region.
- Ankleshwar: Oil from this field is sent to refineries at Trombay and Koyali.

Rajasthan Oilfields

- One of the largest inland oil discoveries was made in Banner district of Rajasthan.
- Other important discoveries == Mangala oil field, Sarswati and Rajeshwari.
- Rajasthan is the largest on shore oil producing state of India.

Off-Shore Production in India

Western Coast

- **Mumbai High, Bassein** and **Aliabet**.
- Mumbai High: 1974; rock strata of Miocene age.
- Sagar Samrat, Bassein: south of Mumbai High.
- Aliabet: Aliabet island in the Gulf of Khambhat.

Eastern Coast

- The basin and delta regions of the **Godawari, the Krishna and the Cauvery** rivers hold great potential for oil and gas production.

Crude Oil and LPG Pipelines of India
N
AFGHANISTAN
JAMMU & KASHMIR
PAKISTAN
HIMACHAL PRADESH
CHINA
TIBET
Jalandhar
Ambala
Bhatinda
Panipat
Roorkee
Najibabad
HARYANA
ARUNACHAL PRADESH
Delhi
Dadri
NEPAL
Tinsukia
Digboi
Rewari
SIKKIM
BHUTAN
Dibrugarh
Mathura
Tundla
RAJASTHAN
Chaksu
Shahjahanpur
Lucknow
Siliguri
Bongaigaon
ASSAM
NAGALAND
Jodhpur
Ajmer
Sanganer
Dholpur
UTTAR PRADESH
Guwahati
Numaligarh
BIHAR
MEGHALAYA
Auriya
Kanpur
BANGLADESH
Kota
Barauni
MANIPUR
TRIPURA
JHARKHAND
WEST BENGAL
Vijapur
MIZORAM
Kandla
Sidhpur
Rajbandh
Ahmedabad
Mourigram
Jamnagar
Viramgam
Jhabua
MADHYA PRADESH
Budge-Budge
MYANMAR (BURMA)
Salaya
Porbander
Vadodara
Indore
Haldia
Bharuch
Ankleshwar
CHHATTISGARH
ORISSA
Hazira
Manmad
Mumbai
MAHARASHTRA
BAY OF BENGAL
Pune
Hyderabad
TELANGANA
Vishakhapattinam
Vijayawada
GOA
ANDHRA PRADESH
KARNATAKA
ARABIAN SEA
LEGEND
Mangalore
Hassan
Bangalore
Crude Oil Pipeline
LNG Pipeline
LNG Upgradation
Product Pipeline
Sankari
LAKSHADWEEP
TAMIL-NADU
ANDAMAN & NICOBAR ISLANDS (INDIA)
KERALA
Trichy
Karur
Kochi
Map not to Scale
SRI LANKA
Copyright © 2014 www.mapsofindia.com
(Updated on 2nd June 2014)
INDIAN
OCEAN

- The **Rawa field** in Krishna-Godawari off-shore basin is an important one.
- The Narimanam and Kovilappal oilfields in the Cauvery on-shore basin are also important.

Petroleum Refining

- India's first oil refinery started working way back in 1901 at **Digboi in Assam**.
- 1954: another refinery at Tarapur (Mumbai).

- Refinery hub and refining capacity exceeds the demand. Excess refined oil and other petroleum products are exported.
- Oil from wells is transported to nearest refineries through pipelines.

Advantages of Pipeline

- Ideal to transport liquids and gases.
- Pipelines can be laid through difficult terrains as well as under water.
- Economical.
- It needs very little maintenance.
- Pipelines are safe, accident-free and environmental friendly.

Disadvantages of Pipelines

- It is not flexible, i.e., it can be used only for a few fixed points.
- Its capacity cannot be increased once it is laid.
- It is difficult to make security arrangements for pipelines.
- Detection of leakage and repair is also difficult.

Crude Oil Pipelines

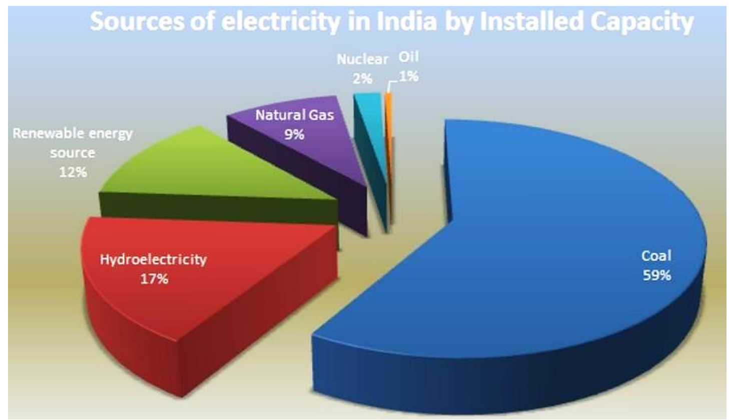
- Salaya-Mathura Pipeline (SMPL)
- Paradip-Haldia-Barauni Pipeline (PHBPL)
- Mundra-Panipat Pipeline (MPPL)

Petroleum Product Pipelines

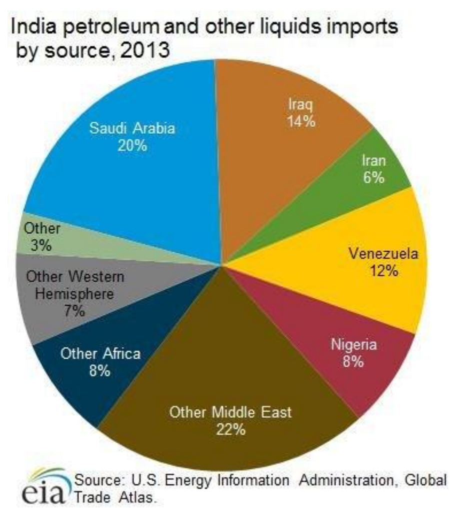
Remember locations of Oil Refineries and Major Oil producing centers. Pipeline are the ones that connect these centers.

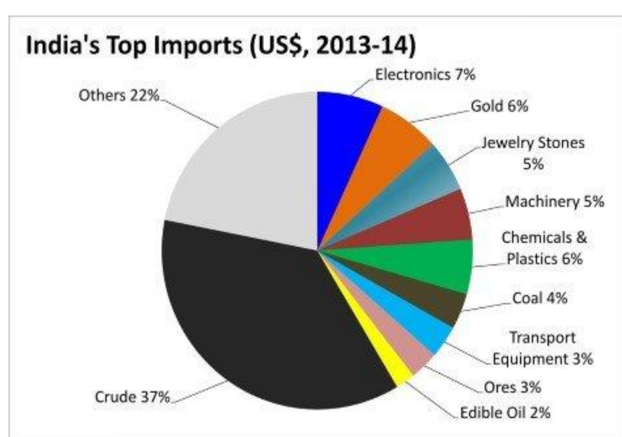
- Guwahati-Siliguri Pipeline (GSPL)
- Koyali-Ahmedabad Pipeline (KAPL)
- Barauni-Kanpur Pipeline (BKPL)
- Panipat-Delhi Pipeline (PDPL)
- Panipat-Rewari Pipeline (PRPL)
- Chennai – Trichy - Madurai Product Pipeline (CTMPL)
- Chennai-Bangalore Pipeline
- Naharkatia-Nunmati-Barauni Pipeline == **first pipeline constructed in India**
- Mumbai High-Mumbai-Ankleshwar-Koyali Pipeline.
- Hajira-Bijapur-Jagdishpur (HBJ) Gas Pipeline == **world's largest underground pipeline**
- Jamnagar-Loni LPG Pipeline == **longest LPG pipeline in the world**
- Kochi-Mangalore-Bangalore pipeline
- Vishakhapatnam Secunderabad pipeline
- Mangalore-Chennai pipeline
- Vijayawada-Vishakhapatnam pipeline

Share of Oil in Power Generation



India's Oil Imports





Petroleum and Mineral Oil – World distribution: Supergiants, Oilfields in Saudi Arabia, Iraq, Kuwait, Iran, Russia, United States, Mexico, Canada, Venezuela, Brazil, United Kingdom and African Region.

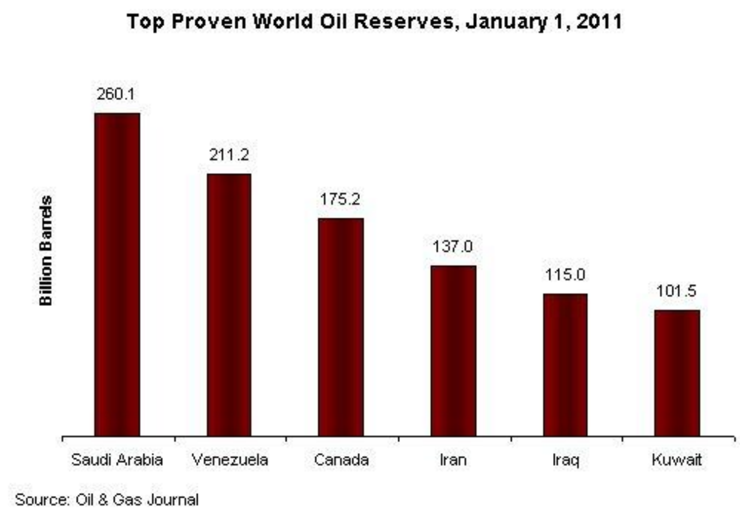
Petroleum and Mineral Oil - World distribution

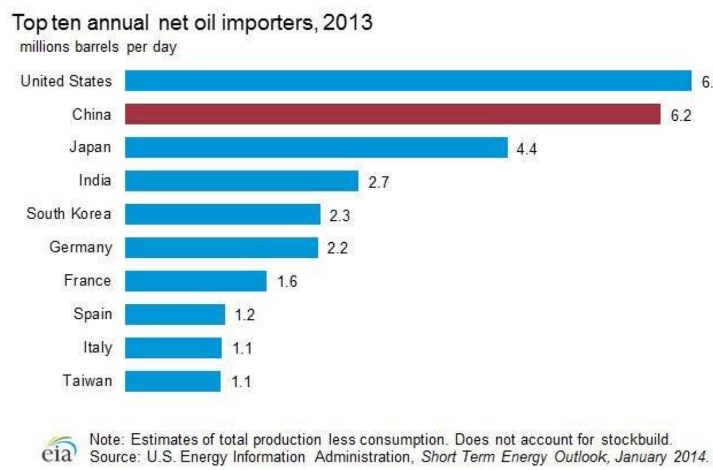
- More than half of the world's proven oil reserves are located in the **Middle East** (including Iran but not North Africa).
- Canada, United States, Latin America, Africa, and the region occupied by the former Soviet Union contains less than **15 percent** of the world's proven reserves.

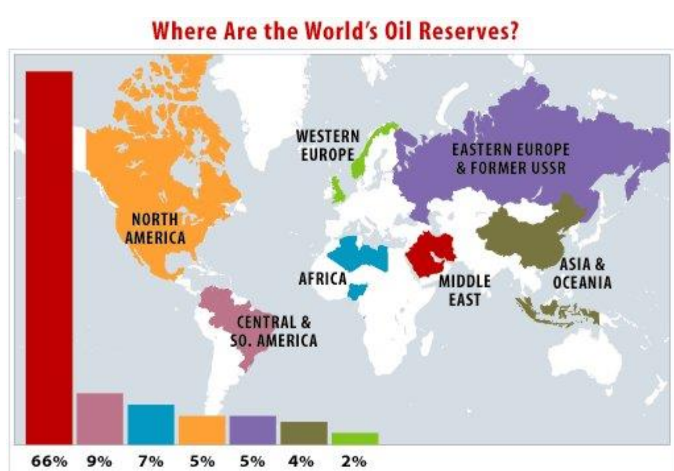
[Reserves are identified quantities of petroleum that are considered recoverable under current economic and technological conditions.]

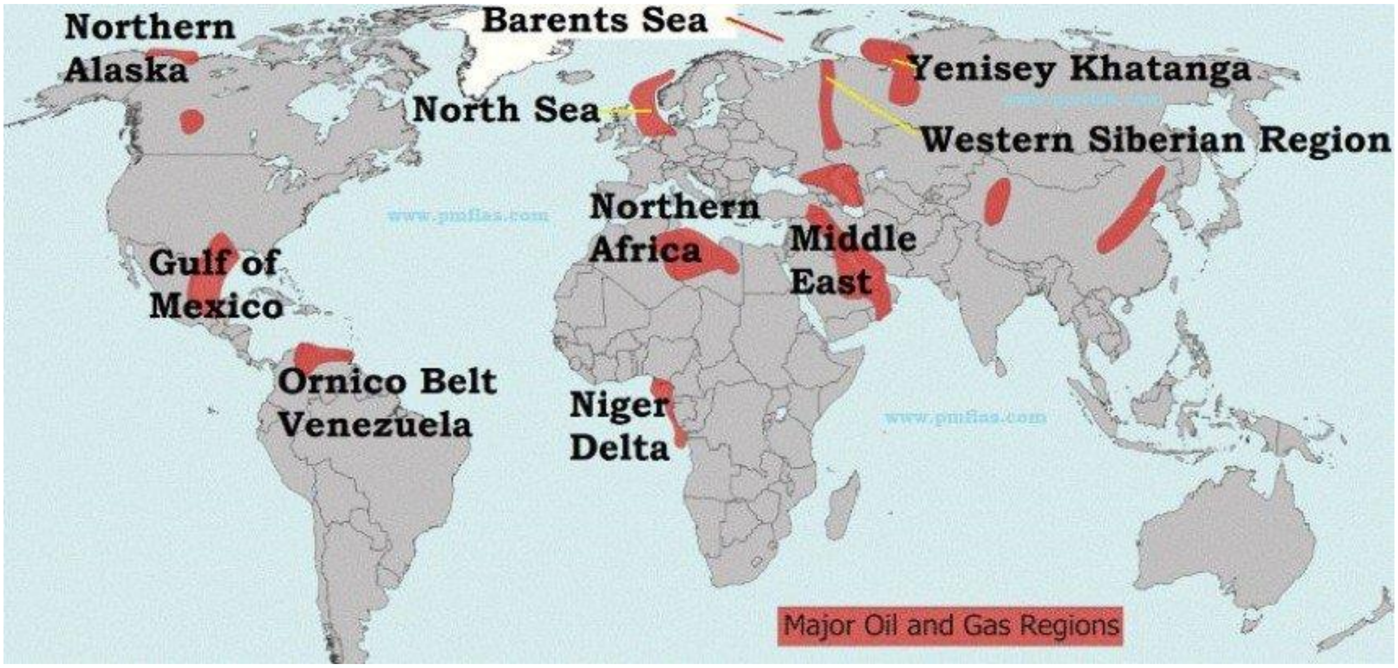
8. Gross Refining Margins	
Company	**Refinery**
IOCL	Barauni
	Koyali
	Haldia
	Mathura
	Panipat
	Guwahati
	Digboi
	Bongaigaon
	Average
BPCL	Kochi
	Mumbai
	Average
HPCL	Mumbai
	Visakhapatnam
	Average
CPCL	Chennai
MRPL	Mangalore
NRL	Numaligarh
BORL	Bina
RIL	Jamnagar
Essar	Vadinar

- The amount of oil a given region produces is not always proportionate to the size of its proven reserves.
- For example, the Middle East contains more than 50 percent of the world's proven reserves but accounts for only about 30 percent of global oil production.
- The United States, by contrast has less than 2 percent of the world's proven reserves but produces about 10 percent of the world's oil.









Supergiants

- Petroleum is contained in a few large fields, but most fields are small.
- The two largest classes of fields are the
1. **supergiants**, fields with 5 billion or more barrels of ultimately recoverable oil, and
2. **world-class giants**, fields with 500 million to 5 billion barrels of recoverable oil.
- Fewer than 40 supergiant oil fields have been found worldwide.
- The **Arabian-Iranian sedimentary basin** in the Persian Gulf region contains **two-thirds** of these supergiant fields.
- The remaining supergiants are distributed in the **United States, Russia, Mexico, Libya, Algeria, Venezuela,** and **China.**

Oilfields in Saudi Arabia

- Saudi Arabia has the **largest proven oil reserves.**
- Approximately 20 percent of the world's proven reserves.
- The discovery that transformed Saudi Arabia into a leading oil country was **Al-Ghawār oil field.** (still has 70 billion barrels after 60 years of production)
- Another important discovery was the **Saffaniyah offshore field in the Persian Gulf.** It is the third largest oil field in the world and the **largest offshore.**

Oil Fields in Iraq, Kuwait, & Iran

- The Middle Eastern countries of Iraq, Kuwait, and Iran are each estimated to have **25 percent** of all proven reserves in the world.

- These countries have a number of supergiant fields.
- **Al-Burqan** oilfield of Kuwait is the world's **second largest oil field**.

Oil Fields in Russia

- Russia is thought to possess the best potential for new discoveries.
- It has significant proven reserves of 5 percent of the world total—and is the **world's leading petroleum producer.**
- There are two supergiant oil fields – Western Siberia and Yenisey Khatanga.
- **Kamchatka peninsula** and **Sakhalin Island** are said to have significant oil reserves.
- Volga-Caspian Region has many oil and gas fields.

Oil Fields in United States, Mexico, & Canada

- North America has many sedimentary basins.
- Many oilfields have been found in **North Slope region of Alaska** and **East Texas.**
- United States has produced more oil than any other country.
- Its proven oil reserves amount to 2 percent of the world total.
- The **Rocky Mountain region** contains an enormous amount of petroleum reserve.
- Mexico has more than 10 billion barrels of proven oil reserves and is one of the top 10 oil producers in the world.
- Canada has less than 10 billion barrels of proven reserves of conventional liquid oil.
- But huge deposits of oil sands in the **Athabasca region in western Canada** bring the country's total proven oil reserves to approximately 175 billion barrels, behind only oil giants **Saudi Arabia** and **Venezuela.**
- Canada's largest oil field is off **Newfoundland.**

Oilfields in Venezuela & Brazil

- Venezuela is the largest oil exporter in the Western Hemisphere.
- 210 billion barrels of proven oil reserves (**world's second largest**).

- Most of these reserves are located in the **Orinoco belt**.
- Brazil has 14 billion barrels of proven oil reserves (second largest in South America)

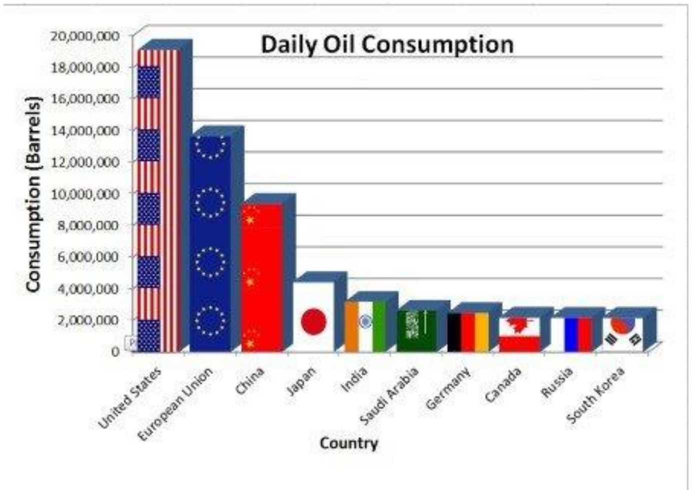
Oilfields in United Kingdom

- The United Kingdom is an important **North Sea producer**, and its proven oil reserves of some three billion barrels are the largest in the European Union.

Oilfields in African Region

- The main oil-producing countries of Africa are: **Libya, Algeria, Nigeria** and **Egypt**.
- Niger delta in Nigeria contains enormous amount of oil.
- Egypt is self-sufficient in oil production.
- Algeria is another significant producer of petroleum where much of the national income comes from oil-export.
- Libya became a consistent producer of petroleum. The total oil reserve of Libya is around 3 per cent of global reserve.

Source:
http://www.britannica.com/science/petroleum/World-distribution-of-oil



Natural gas – World Distribution of Natural Gas, OPEC. Distribution of Natural Gas in India, Petroleum and Gas Value Chain: Upstream, Midstream, Downstream sector.

Natural gas

- Consists primarily of **methane** and **ethane.**
- *Propane, butane, pentane, and hexane* are also present.
- Liquefied petroleum gas (LPG) == Mixture of **butane and propane.**
- Commonly occurs in association with crude oil.
- Natural gas is often found dissolved in oil or as a gas cap above the oil.
- Sometimes, pressure of natural gas forces oil up to the surface. Such natural gas is known as **associated gas or wet gas.**
- Some reservoirs contain gas and **no oil**. This gas is termed **non-associated gas or dry gas.**
- Often natural gases contain substantial quantities of **hydrogen sulfide** or other organic sulfur compounds. In this case, the gas is known as **"sour gas."**
- Coalbed methane is called **'sweet gas'** because of its lack of hydrogen sulfide.

Oil + Gas == Associated Gas – Wet Gas,

Only Gas == Non-Associated Gas – Dry Gas,

Hydrogen Sulphide in gas == Sour Gas,

Coalbed Methane == Sweet Gas.

- On the market, natural gas is usually bought and sold not by volume but by **calorific value.**
- In practice, purchases of natural gas are usually denoted as MMBTUs (millions of British thermal unit (BTU or Btu)) = ~1,000 cubic feet of natural gas.

Natural Gas Formation

- Similar to the ***formation of Petroleum***.
- Natural gas was formed millions of years ago when plants and tiny sea animals were buried by sand and rock.
- Layers of mud, sand, rock, plant, and animal matter continued to build up until the pressure and heat turned them into oil and natural gas.

Uses of Natural Gas

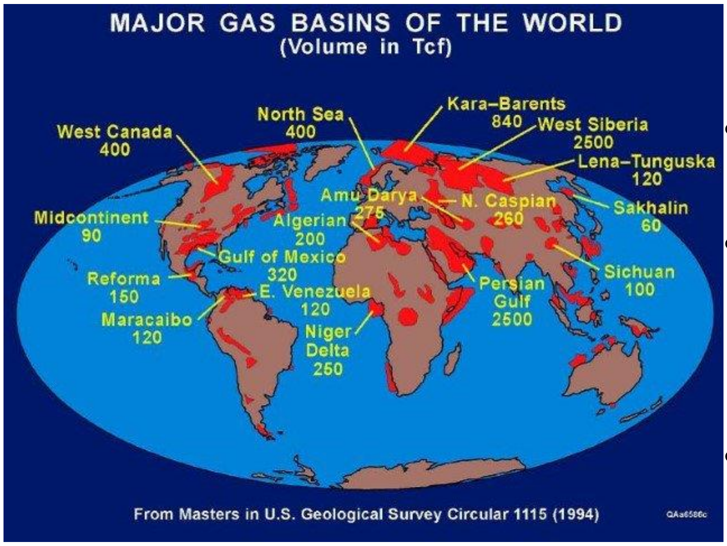
- Electric power generation.
- Industrial, domestic, and commercial usage.
- Many buses and commercial automotive fleets now operate on CNG.
- It is an ingredient in dyes and inks .
- Used in rubber compounding operations.
- **Ammonia** is manufactured using hydrogen derived from methane. Ammonia is used to produce chemicals such as hydrogen cyanide, nitric acid, urea, and a range of fertilizers.

Importance of Natural Gas to India

- Power stations using gas accounted for nearly 10 per cent of India's electricity.
- Despite the country reeling under a power crisis, gas power stations are lying idle due to lack of feedstock.
- The Government has frozen the construction of new gas plants until 2015-16 because of gas shortages.

- Existing plants are operating below capacity on expensive imported liquefied natural gas (LNG).
- India's oil reserves are insufficient for its growing energy needs and situation is made worse by policy paralysis which increases the gestation period of the projects.
- We need to **diversify our energy basket** through alternate fuels so that we need not have to bear the brunt of external shocks.

World Distribution of Natural Gas



Natural Gas in Russia

- Russia has the **largest natural gas reserves** in the world (1,680 Trillion Cubic Feet (tcf)).
- It periodically changes place with the United States as the **world's largest or second largest producer.**
- Some of the world's largest gas fields occur in a region of **West Siberia** and east of the **Gulf of Ob on the Arctic Circle**.
- The world's largest gas field is **Urengoy.**
- **Volga-Urals** region also has significant gas reserves.

Natural Gas in Europe

- **Dutch coast** and the **North Sea** (off the coast of Norway) have proven reserves.

Natural Gas in North America

- The United States has proven natural gas reserves of 273 tcf.
- Its largest gas field, Hugoton extends through the **Oklahoma, Texas and Kansas**.
- Canada has an estimated 62 tcf of proven natural gas reserves.
- The largest gas field is in **Alberta**.
- Much of Mexico's natural comes from **Gulf of Mexico**.

Natural Gas in Africa

- Central basin of **Algeria** and **Niger Delta** have proven reserves.

Natural Gas in Middle East

- There is an enormous gas potential in the Middle East associated with the major oil fields in the **Arabian-Iranian basin.**
- **Iran** and **Qatar** have the second and third largest natural gas reserves in the world, behind Russia.

Natural Gas in Asia

- The largest gas field in Asia is in the **North Sumatra basin of Indonesia**.

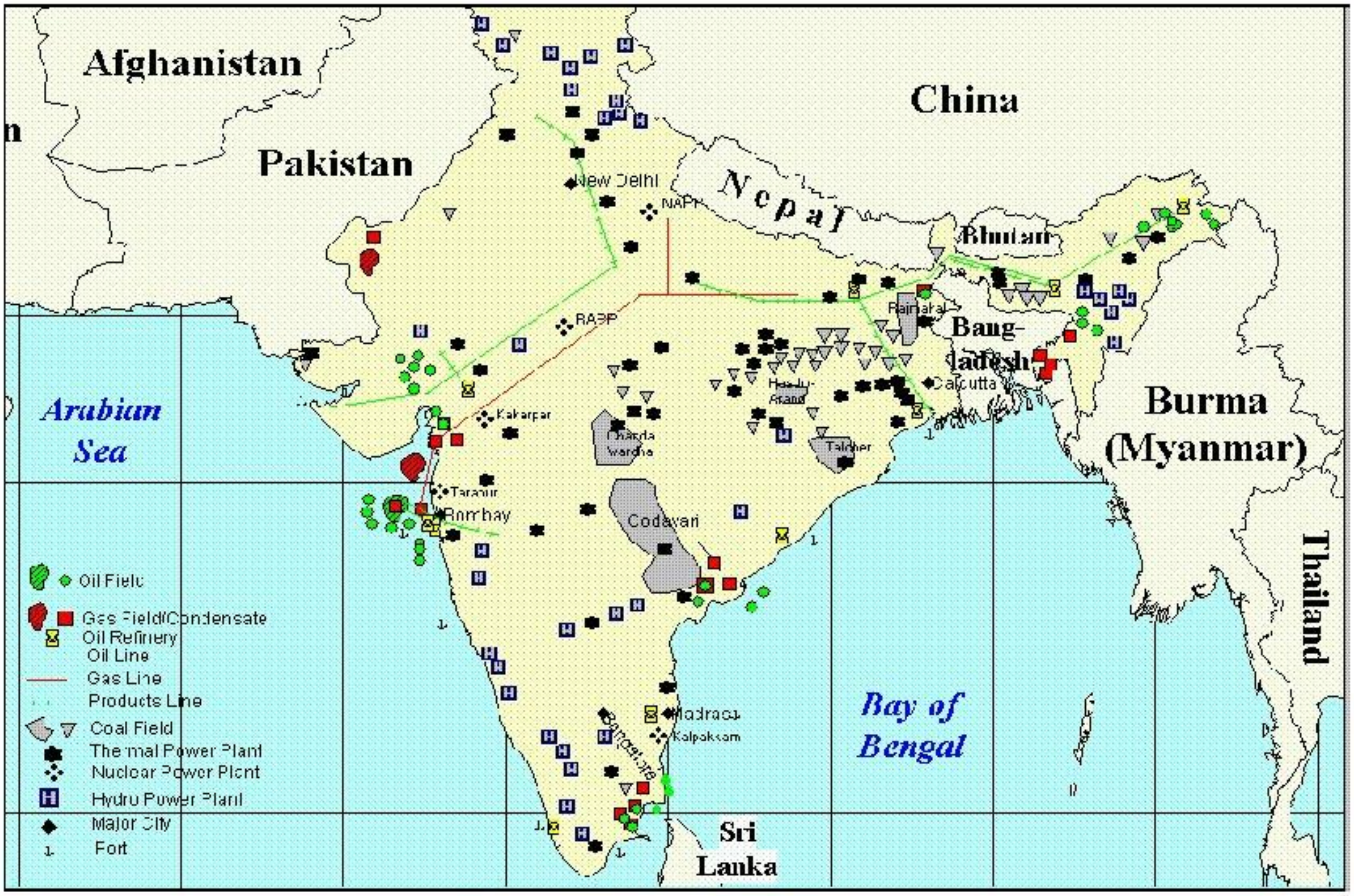
OPEC – Organization of Petroleum Exporting Countries

- 12 member oil supply cartel.
- Iran, Iraq, Kuwait, Saudi Arabia, Venezuela, and later joined by Qatar, Indonesia, UAE, Libya, Algeria, Nigeria, Gabon and Angola.
- This group bargains with international Oil Companies so that profit margin will be high.
- They control production and supply [for better profit margin] of crude oil to keep it below international demand.
- It is only recently that Crude oil's prices have crashed due to **shale boom in US** — the largest importer of oil and gas.

Distribution of Natural Gas in India

- KG basin, Assam, Gulf of Khambhat, Cuddalore district of Tamil Nadu, Barmer in Rajasthan etc.

ENERGY MAP OF INDIA



Petroleum – Value Chain

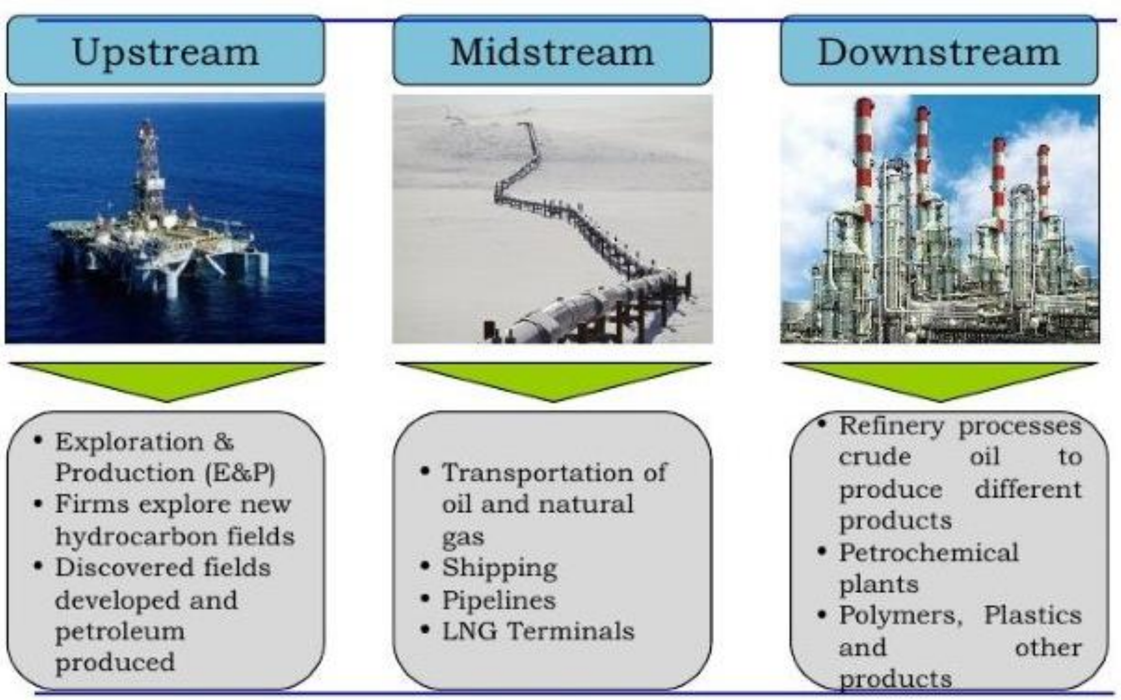
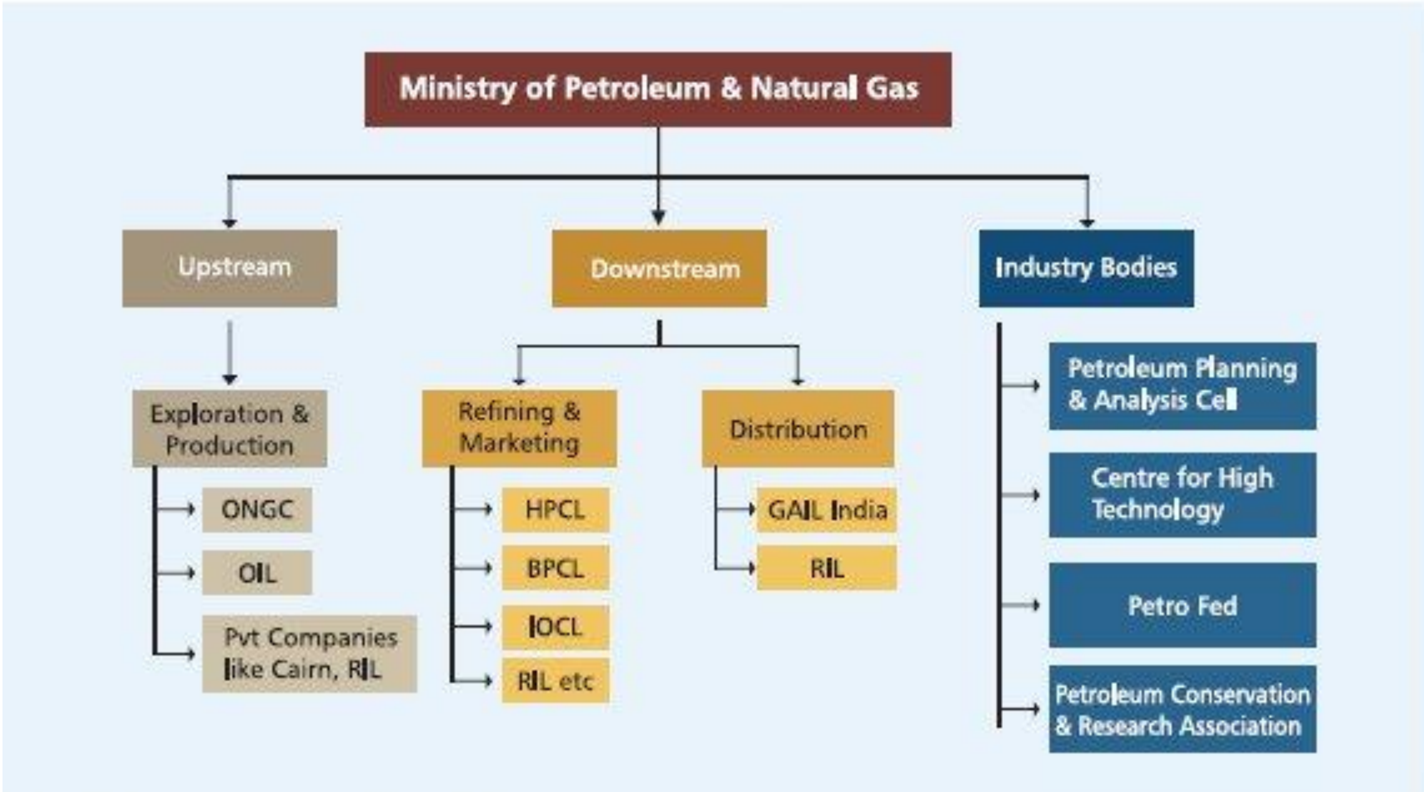
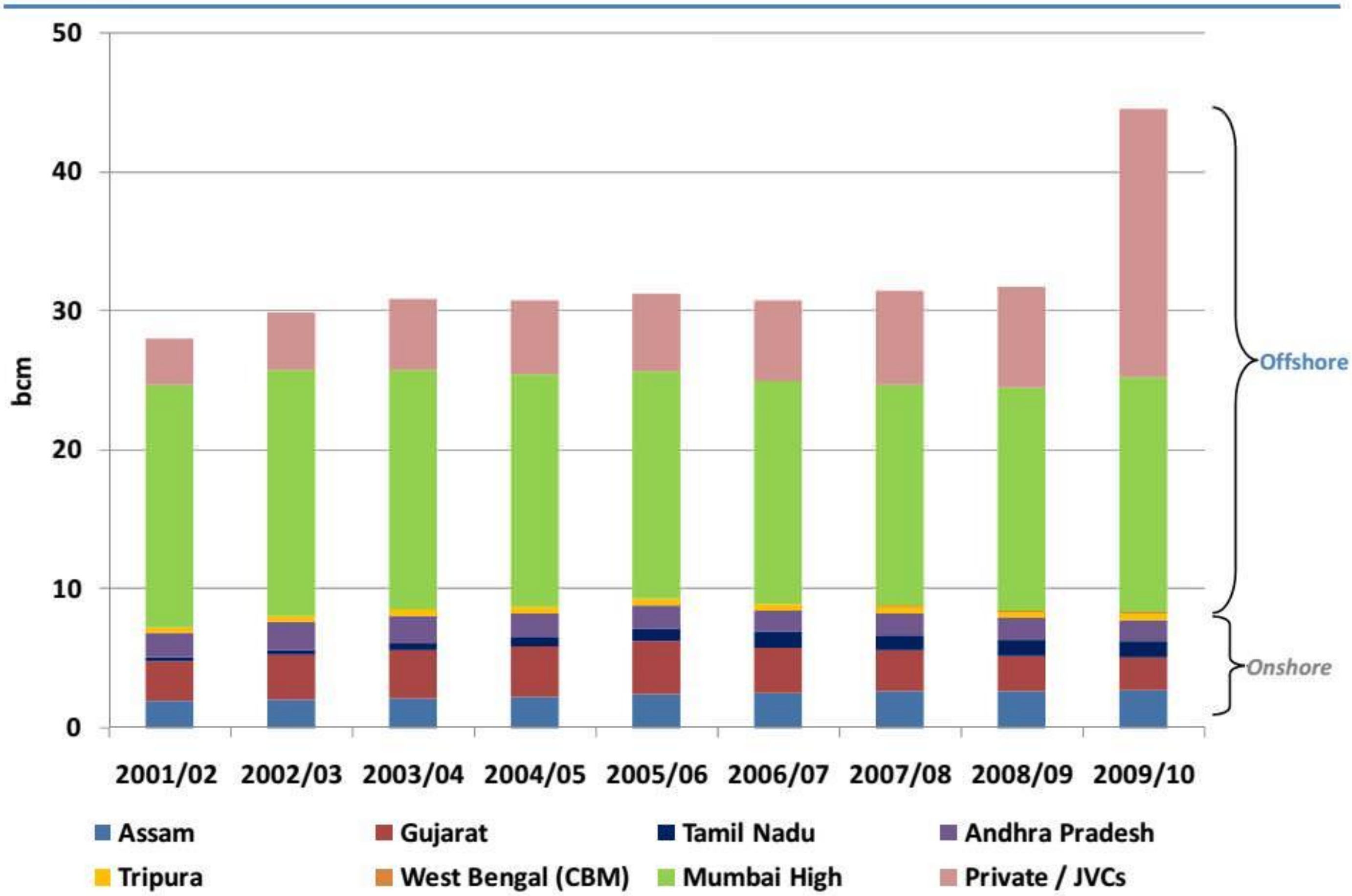


Exhibit 3.1: Structure of Indian Oil & Gas Industry

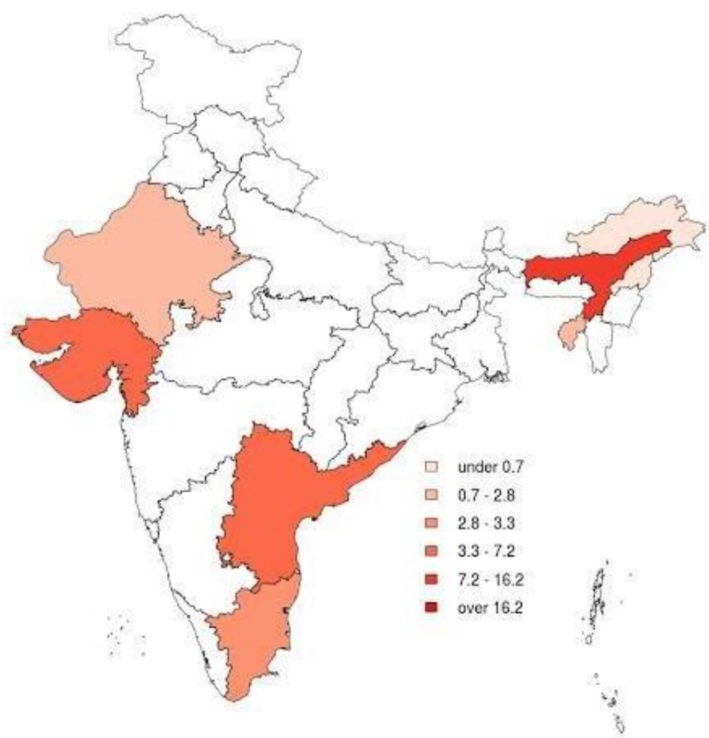


Source: Ministry of Petroleum & Natural Gas

Figure 1: Domestic net gas production by region



Distribution% of Natural Gas Reserves - as of 31st March 2011



Petroleum and Gas Value Chain

- Oil & gas industry is divided in Upstream, Midstream and Downstream sector.

Upstream Sector

- Oil exploration, prospection and extraction/production from oil wells.

New Exploration Licensing Policy, 1997

- Promote exploration by providing a level playing field to private players against public enterprises.
- Oil blocks are allotted under 'Production Sharing Contracts'.
- In 'Production Sharing Contracts', investment and revenues is shared with government.
- The private companies exaggerated or inflated their investment accounts and gobbled up public funds.

Open Acreage Licensing Policy (OALP)

- There are demands to replace NELP with OALP.
- Under OALP, oil blocks will be available throughout for sale. [government makes money by selling oilfields]
- It allows ample time for explorer to study the fields and bid for block of his choice.
- 'National Data Repository' is prerequisite for functioning of OALP.
- It will be a 'hydrocarbon data center' which facilitate prospection of resources.

Revenue Sharing Contracts

- Seen as a better alternative to OALP and NELP.
- Government gets share in revenue from the very beginning.
- In contrast PSC (Production Sharing Contracts), allows government to have revenue share only after costs are recovered by the explorer.
- In PSC, explorers inflate investment by classifying revenue expenditure (salaries, maintenance etc.) as capital expenditure (equipment, technology etc.).
- This resulted in lower government share. It delays revenue to the government by decades.

Kelkar Committee Recommendations

- Deep sea offshore Blocks – Production Sharing Contracts should be adopted.
- Onshore and Shallow blocks – Revenue Sharing Model should be adopted.

Rangarajan Committee Recommendations

- Suggested linking gas price to price of imported gas and gas prices prevailing in exchanges of USA, UK and Japan (weighted average) so as to bring it at parity with international prices.
- This would result in increase of price from $ 4.2 mmbtu to$ 8.4 mmbtu, this formulae was not implemented (it will do serious damage to vote bank).

Midstream sector

- This sector involves transportation of oil and gas from blocks to refineries and from refineries to distribution centers.
- Most cost effective way is through **pipeline**, in comparison to road and railways which higher economic and environmental costs.
- Current pipeline infrastructure is skewed in favor of North and West India, which accounts for 60% of gas pipelines and 80 % of gas consumptions.
- To remedy this, central government has proposed to set up **National Gas Grid** under which additional 15000 km of pipelines will be laid down.
- It will be executed under PPP model and will be eligible for 'Viability Gap Funding'.
- Further, Gas Distribution networks are available in only few cities. In most of cities gas is transferred through bottling plants and distribution agency. This result in wastage by leakages and theft.

Viability Gap Funding

- In some PPP projects in India, Central and state governments undertake to provide support funding to successful bidders.
- Projects are awarded to those whose requirement for state funding is least.
- Indian Oil Corporation and Gas Authority of India are involved in this sector.

Storage

- Government is building underground storage capacity of 15 million metric tons for petroleum and related products.
- The first phase construction is in progress in Vishakhapatnam, Mangalore and Padur [All coastal cities].
- Storage facilities are essential for safeguard against shortages or supply disruptions.

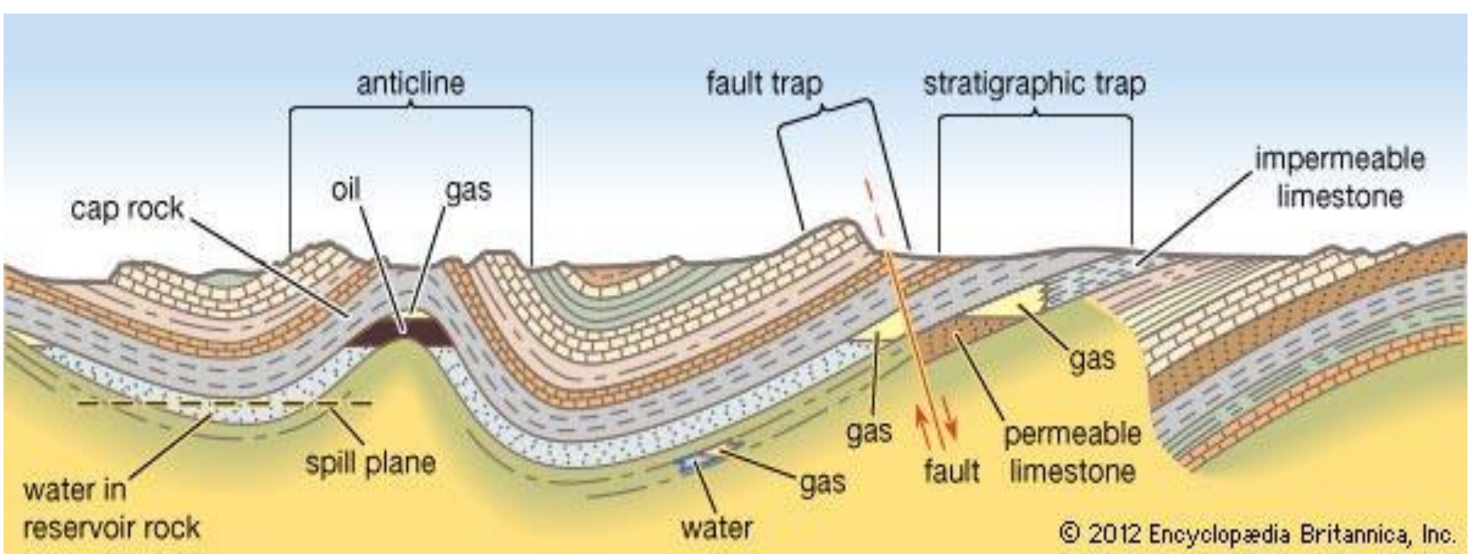
Downstream sector

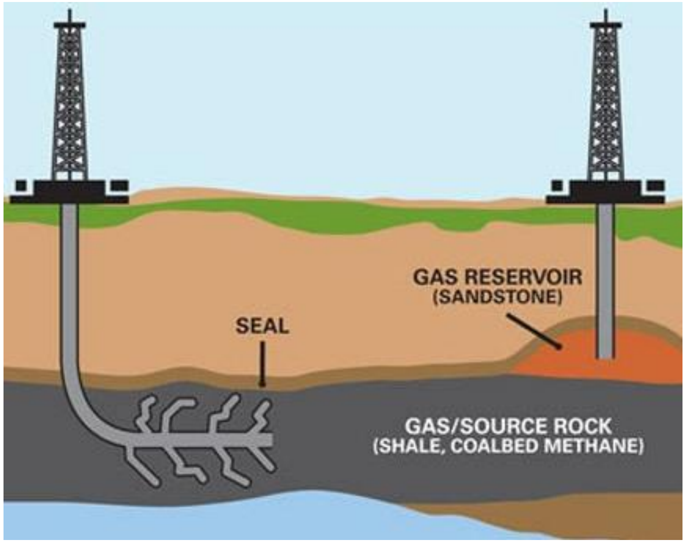
- This sector involves refining, processing and marketing of products and byproducts of crude oil.

Unconventional Gas Reservoirs: Shale Gas – Coalbed Methane. Shale Gas Reserves India, World. Extraction of Shale Gas: Hydro-fracturing or Fracking. Problems Associated.

Unconventional Gas Reservoirs

- Conventional reservoirs of oil and natural gas are found in **permeable sandstone.**
- Unconventional Gas Reservoirs occur in relatively **impermeable sandstones**, in joints and fractures or absorbed into the matrix of shales [Shale is **a Sedimentary Rock**], and in **coal** seams.
- Given current economic conditions and state of technology, they are more expensive to exploit.
- **Example: Tight gas, shale gas,** and **coal-bed methane.**





Coalbed Methane

- Considerable quantities of **methane** is trapped within coal seams.
- A significant portion of this gas remains as free gas in the joints and fractures of the coal seam.
- Large quantities of gas are adsorbed on the internal surfaces of the micropores within the coal itself.
- This gas can be accessed by drilling wells into the coal seam and **pumping large quantities of water** that saturate the seam. [water will occupy the gaps and pores and will push out the gas]
- It is now becoming an important source of **natural gas**.
- Unlike much natural gas from conventional reservoirs, coalbed methane contains **very little heavier hydrocarbons** such as **propane or butane**.
- The presence of this gas is well known from its occurrence in underground coal mining, where it presents a **serious safety risk**.

Fire Accidents in Coal Mines are mainly due to **Coalbed Methane,** and Lignite deposits which undergo **spontaneous combustion**.

Coalbed Methane in India

- With one of the largest proven coal reserves, and one of the largest coal producer in the world, India holds significant prospects for commercial recovery of coalbed methane.
- The country has an estimated 700-950 billion cubic metre of coalbed methane.

Problems in Exploration, Extraction of Coalbed Methane in India

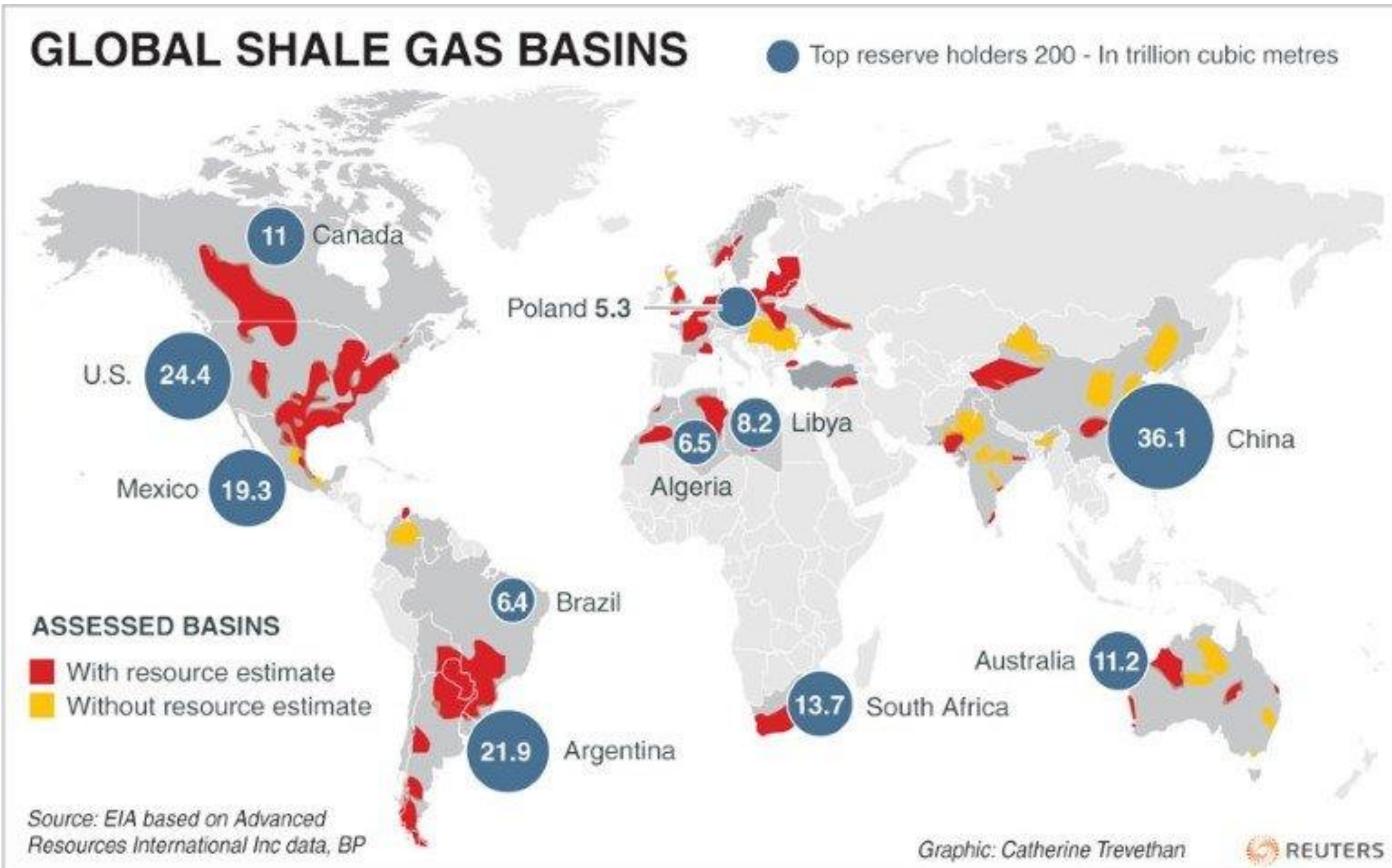
- The state-run firms are holding mines in joint venture with private companies and the latter do not have rights to explore coalbed methane [private sector companies at present have no rights to extract unconventional gas reservoirs — coalbed methane and shale gas].
- CBM extraction falls under **Ministry of Petroleum & Natural Gas** whereas coal mining falls under **Ministry of Coal**. Contractors are not allowed to mine gas from coal seams or coal bed methane (CBM) and coal in the same block due to the **turf war** [common feature of Indian Bureaucracy] between the two ministries and other associated bureaucratic hurdles.
- Extracting unconventional gas is a capital intensive process and at the present levels of gas prices, the companies cannot recover their investments.
- The technology required is very advanced and the public sector companies have very weak organizational setup to efficiently handle such technologies and extract gas economically.
- Private sector companies have necessary financial capabilities and managerial skills but there is no hope due to restricting laws and low gas prices.

In India, gas pricing is a contentious issue. It has never been easy satisfying all the stakeholders involved [consumer, government, gas companies]. Gas pricing will be critical for private companies before they can invest in unconventional gas projects so that they can calculate their profit margin.

Shale Gas – Shale Gas Formation

- Shale gas = Lot of ***Methane*** + Little ***Ethane, Propane, & Butane*** + very little ***carbon dioxide, nitrogen, and hydrogen sulfide***.
- Shales are **fine-grained sedimentary rocks** formed of organic-rich mud at the bottom of ancient seas.
- Subsequent sedimentation and the resultant heat and pressure transformed the mud into shale and also produced natural gas from the organic matter contained in it.
- Over long spans of geologic time, some of the gas migrated to adjacent **sandstones** and was trapped in them, forming conventional gas accumulations.
- The rest of the gas remained **locked** in the **nonporous shale**.

Shale Gas Reserves Across the World

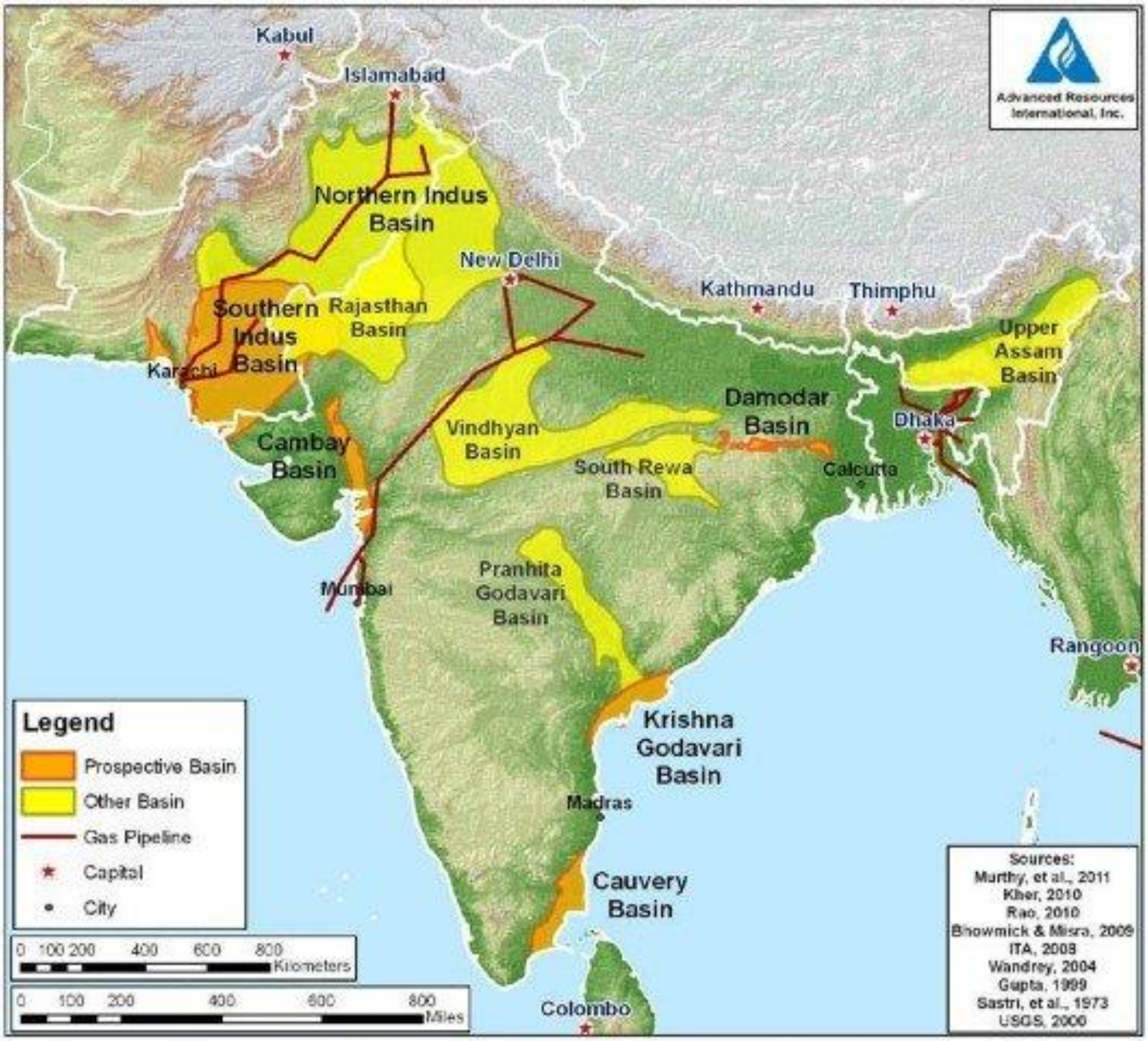


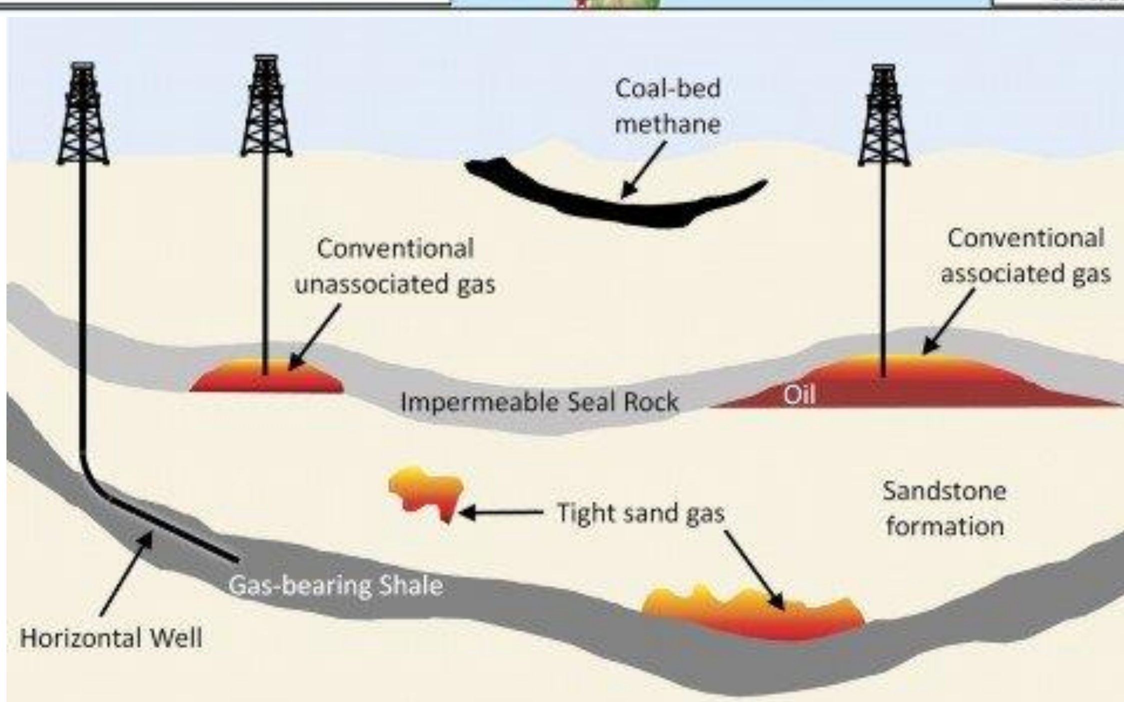
Shale Gas Reserves in India

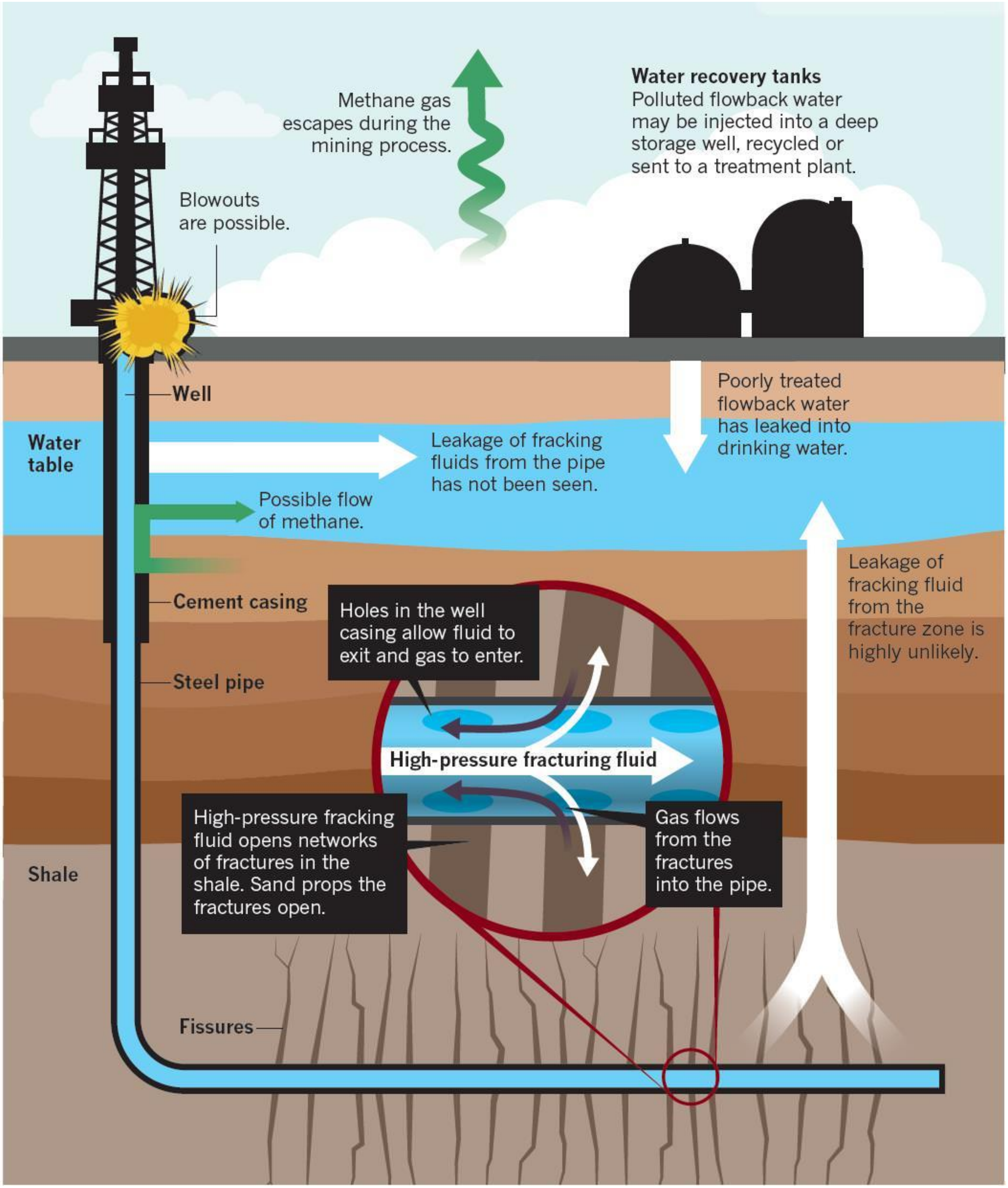
- Basins of preliminary interest identified by Indian geologists are the Cambay Basin in Gujarat, the Assam-Arakan basin in northeast India, and the Gondwana Basin.
- Indian engineers have gathered experience on fracking - the technology to find shale gas - by spending time in the US and are now able to hunt for the scarce resource on their own.
- Fracking technology sends high pressure streams of water, sand and chemicals into shale formations to bring up the oil and gas.
- Environmentalists have objected to fracking because of the **damage to forest cover and possible contamination of ground water.**
- One estimate by Indian scientists places potential reserves at as high as **527 tcf.**

Extraction of Shale Gas

- Shale gas occurs frequently at depths exceeding 1,500 metres (5,000 feet).
- Extraction is done through **horizontal drilling** through the shale seam, followed by **hydraulic fracturing**, or **fracking**, of the rock by the injecting of fluid at extremely high pressure.


Kabul
Islamabad
Advanced Resources International, Inc.
Northern Indus Basin
New Delhi
Kathmandu
Thimphu
Southern Indus Basin
Rajasthan Basin
Karachi
Upper Assam Basin
Damodar Basin
Dhaka
Cambay Basin
Vindhyan Basin
South Rewa Basin
Calcutta
Pranhita Godavari Basin
Mumbai
Rangoon
Legend
Prospective Basin
Other Basin
Gas Pipeline
Capital
City
Krishna Godavari Basin
Madras
Cauvery Basin
0 100 200 400 600 800 Kilometers
0 100 200 400 600 800 Miles
Colombo
Sources:
Murthy, et al., 2011
Kher, 2010
Rao, 2010
Bhowmick & Misra, 2009
ITA, 2008
Wandrey, 2004
Gupta, 1999
Sastri, et al., 1973
USGS, 2000


Coal-bed methane
Conventional unassociated gas
Conventional associated gas
Impermeable Seal Rock
Oil
Sandstone formation
Tight sand gas
Gas-bearing Shale
Horizontal Well



Hydro-fracturing or Fracking

- Shale rock is sometimes found 3,000 metres below the surface.
- After deep vertical drilling, there are techniques to **drill horizontally** for considerable distances in various directions to extract the gas-rich shale.
- A mixture of water, chemicals, and sand is then injected into the well at very high pressures to create a number of **fissures** in the rock to release the gas.

- The process of using water for breaking up the rock is known as 'hydro-fracturing' or 'fracking'.
- The chemicals help in water and gas flow and tiny particles of **sand enter the fissures to keep them open** and allow the gas to flow to the surface.

Guar gum

- Can quickly turn water into a **very thick gel**.
- Adding guar gum **increases viscosity of water** and **makes high-pressure pumping and the fracturing process more efficient.**
- High viscosity water is much more effective at suspending sand grains and carrying them into the fractures.
- The guar been is grown mainly by farmers in **Rajasthan** and **Haryana**.
- Earlier, guar gum was used mainly as an additive in ice creams and sauces.
- But with the discovery of its use in shale gas extraction, its **price shot up enormously.**

Problems Associated With Shale Gas Exploitation

- Environmentalists have objected to fracking because of the damage to forest cover and **possible** contamination of ground water.
- However, industry officials say that the treated water can be **re-used** for further fracking and need not be disposed of at all.

Solutions

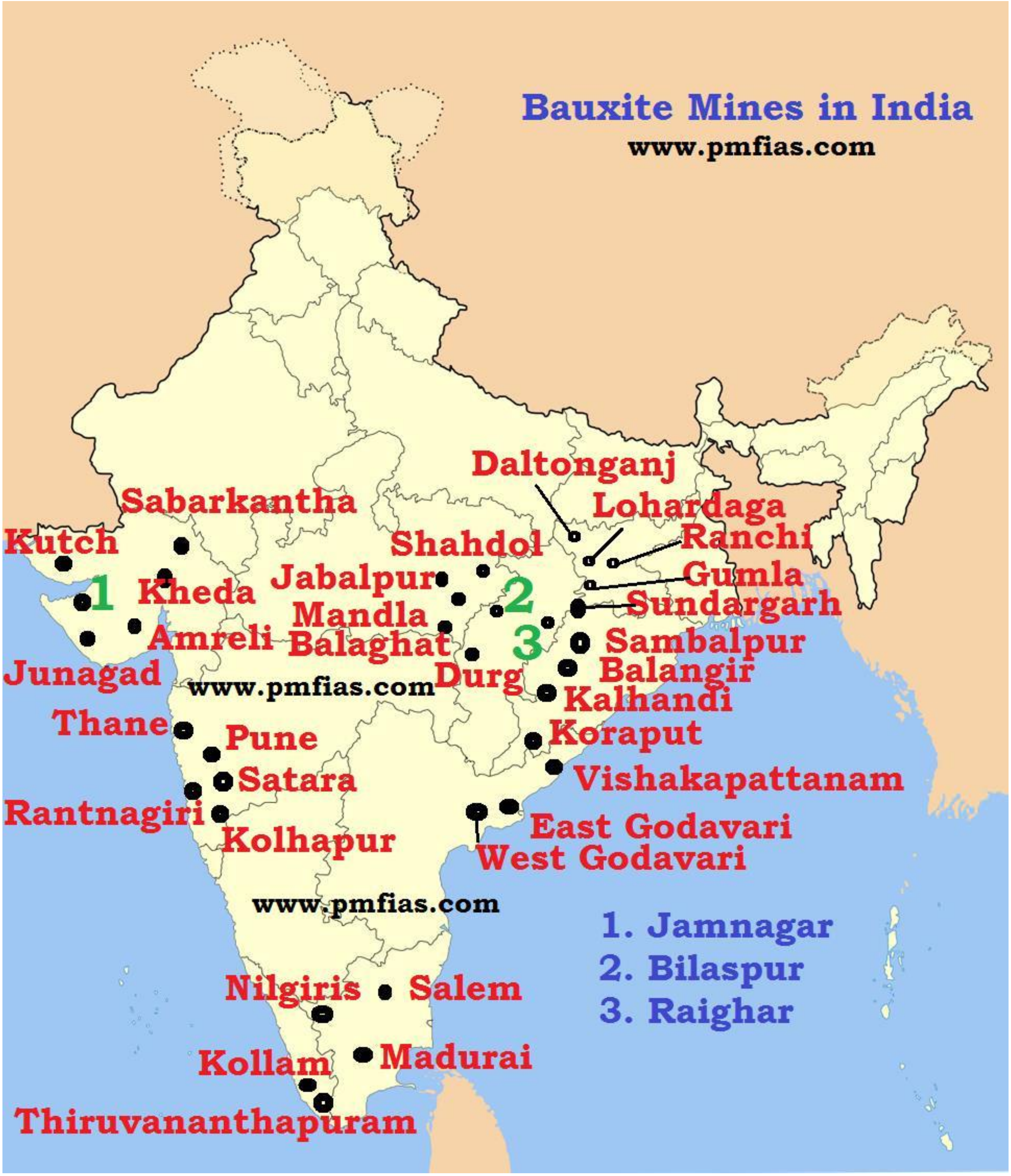
- All the water required must be obtained from rain water harvesting.
- Recycling and reusing of water utilized for fracking should be the preferred method for water management.
- Enforcing clear and practical legislation on environmental and water issues.
- **Coal bed methane (CBM), which is extracted from coal beds, is also an unconventional gas and, in terms of depth, occurs much closer to the land surface than shale gas.**

Shale Gas Extraction Issues in India - If US can then why can't India?

- India suffers from physical and economic **water scarcity** whereas the U.S. do not have the same water worries.
- In the US, the natural gas department is exempt from scrutiny for chemical injection in the ground (it exempts companies from disclosing the chemicals used during hydraulic fracturing). There is no such legislation in India.
- In US, the citizen or resident owns the resources that lie beneath the ground. In India, soil below the land is a public property and the companies must follow all the necessary rules to acquire it.
- The US has mapped all its shale reserves. In India there is clarity on the exact recoverable shale reserves.
- The population density is much lower in the US and they can afford to do it.
- Government-issued leases for conventional petroleum exploration do not include unconventional sources such as shale gas.
- All locations in US is well connected with gas pipelines. Bulk of the reserves in eastern India lack the necessary network of pipelines to transport the gas–a task that many private operators are wary about undertaking.

Shale Gas: Low Potential, High Risk and a Better Alternative

- India has 293 billion tonnes of coal lying under its soil. Extraction is complicated because of environmental issues.
- But, **'underground coal gasification'**, can create 6,900 trillion cubic feet of gas which is way **HIGHER** than shale reserves.
- India's shale resources at a more modest 65 trillion cubic feet. India's CBM potential is estimated at 450 tcf.
- So, focus must be on CBM exploration rather than on risky shale business.



Mains 2013

It is said that India has substantial reserves of shale oil and gas, which can feed the needs of the country. However, tapping of resourced does not appear to be high on the agenda. Discuss critically the availability and issues involved. (10 marks - 200 words)

Answer Yourself with the help of above points.

Distribution of Key Natural Resources across India and World. Bauxite | Lead & Zinc | Tungsten | Pyrites Distribution in India & World.

Bauxite

- 80 % of bauxite [ore of aluminium] ore is used for making **aluminium**.
- Found mainly as hydrated aluminium oxides.
- Total resources == 3,480 million tonnes == 84 per cent resource are of metallurgical grade

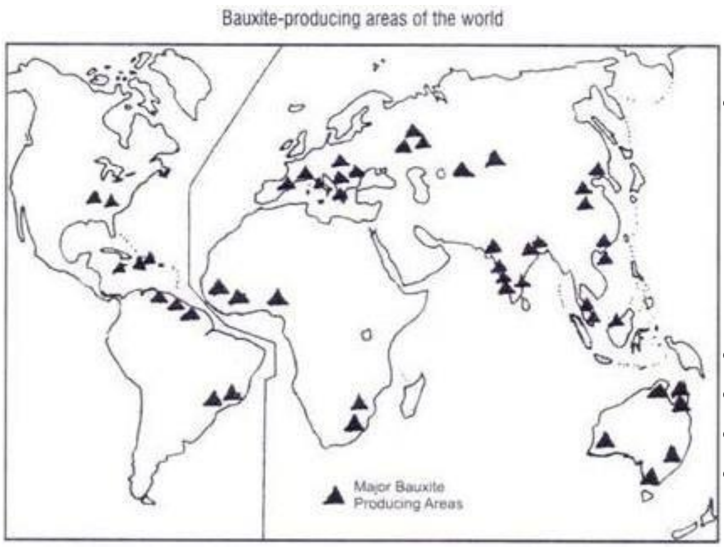
(Source: US Geological Survey, Mineral Commodity Summaries, 2006, fig. for 2005)

Bauxite Distribution in India

- **Odisha** alone accounts for 52 per cent
- Andhra Pradesh 18 per cent
- Gujarat 7 per cent
- Chhattisgarh and Maharashtra 5 per cent each
- Madhya Pradesh and Jharkhand 4 per cent.
- Major bauxite resources are in the east coast in Odisha and Andhra Pradesh.
- India manages to export small quantities of bauxite.
- Major importers are Italy (60%), U.K. (25%), Germany (9%) and Japan (4%).

Odisha

- Largest bauxite producing state.
- One-third of the total production of India.



- Kalahandi and Koraput districts.
- Extends further into Andhra Pradesh
- The main deposits occur in Kalahandi, Koraput, Sundargarh, Bolangir and Sambalpur districts.

Chhattisgarh

- Second largest producer.
- Maikala range in Bilaspur, Durg districts and the Amarkantak plateau regions of Surguja, Raigarh and Bilaspur are some of the areas having rich deposits of bauxite.

Maharashtra

- Third largest producer.
- Largest deposits occur in Kolhapur district.
- Kolhapur district contain rich deposits with alumina content 52 to 89 per cent.
- Other districts: Thane, Ratnagiri, Satara and Pune.

Jharkhand

- Ranchi, Lohardaga, Palamu and Gumla districts.
- High grade ore occurs in Lohardaga.

Gujarat

- Jamnagar, Junagadh, Kheda, Kachchh, Sabarkantha, Amreli and Bhavnagar.
- The most important deposits occur in a belt lying between the Gulf of Kachchh and the Arabian sea through Bhavnagar, Junagadh and Amreli districts.
- Amarkantak plateau area, the Maikala range in Shandol, Mandla and Balaghat districts and the Kotni area of Jabalpur district are the main producers.

Bauxite Distribution – World

- **Australia (31.34%)**,
- China (18.41%),
- Brazil (13.93%),
- Guinea (8.36%), etc.

Lead

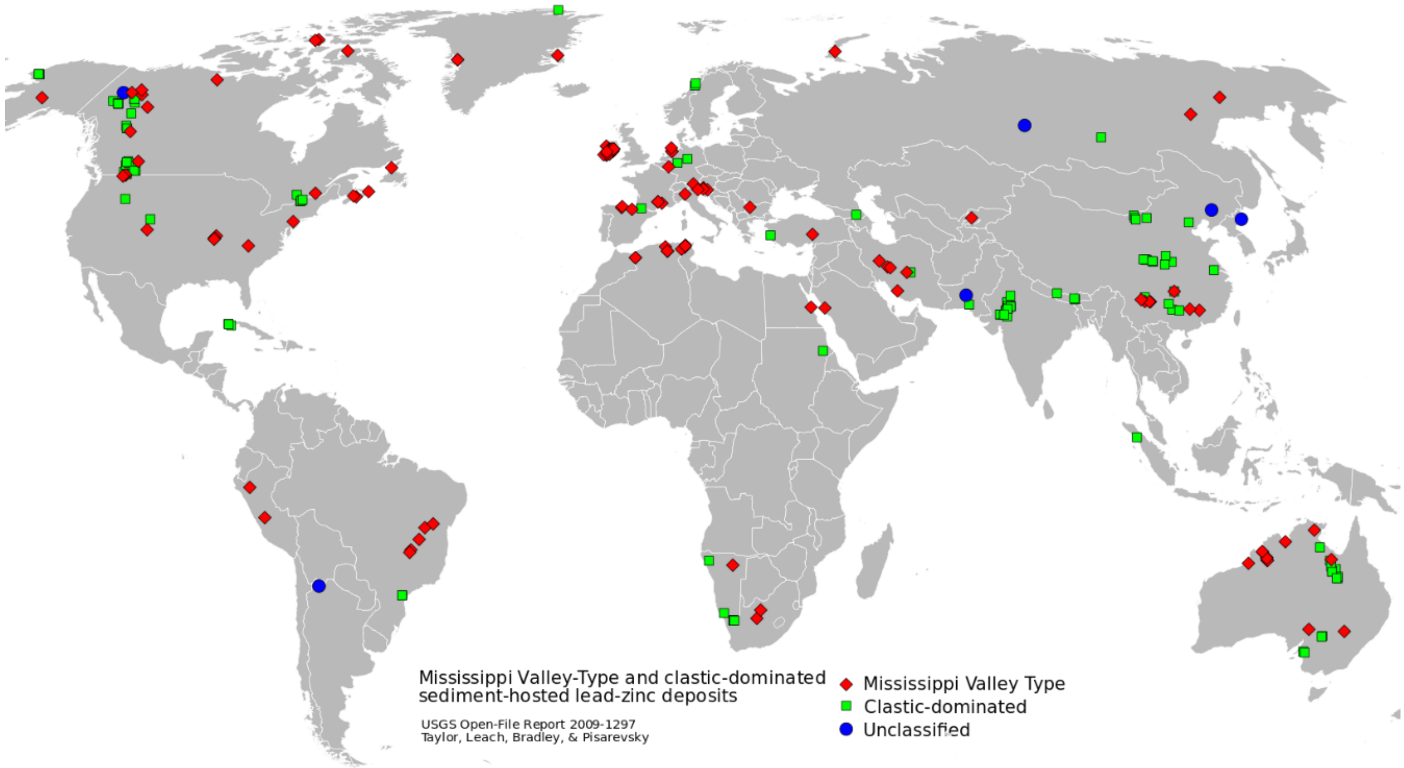
- Malleable [can be hammered into thin sheets], soft, heavy and **bad conductor**.
- Lead is a constituent in bronze alloy and is used as an **anti-friction metal**.
- Lead oxide is used in cable covers, ammunition, paints, glass making and rubber industry.
- It is also made into sheets, tubes and pipes which are used as sanitary fittings.
- It is now increasingly used in automobiles, aeroplanes, and calculating machines.
- Lead nitrate is used in dyeing and printing.
- Lead does not occur free in nature. It occurs as a **cubic sulphide** known as **GALENA**.
- Galena is found in veins in limestones, calcareous slates and sandstones.

Zinc

- Zinc is a **mixed ore** containing **lead & zinc**.
- Zinc is found in veins in association with galena, chalcopyrites, iron pyrites and other **sulphide ores**.
- It is mainly used for alloying and for manufacturing **galvanized sheets**.
- It is also used for dry batteries, electrodes, textiles, die-casting, rubber industry and for making collapsible tubes containing drugs, pastes and the like.

Distribution of Lead and Zinc ores - India and World

- **Rajasthan** is endowed with the largest resources of lead-zinc ore (88.61 per cent),
- Andhra Pradesh (3.31 per cent),
- Madhya Pradesh (2.16 per cent),
- Bihar (1.67 per cent)
- Maharashtra 9 (1.35 per cent).
- Almost the entire production comes from **Rajasthan**.



Tungsten

- Ore of Tungsten is called **WOLFRAM.**
- Most important property is that of **self-hardening** which it imparts to steel.
- Over 95 per cent of the worlfram is used by the steel industry.
- Steel containing the requisite proportion of tungsten is mainly used in manufacturing amunitions, armour plates, heavy guns, hard cutting tools, etc.
- Tungsten is easily alloyed with chromium, nickel, molybdenum, titanium, etc. to yield a number of hard facing, heat and corrosion resistant alloys.
- It is also used for various other purposes such as **electric bulb filaments**, paints, ceramics, textiles, etc.

Distribution of Wolfram

- Karnataka (42 per cent)
- Rajasthan (27 per cent)
- Andhra Pradesh (17 per cent)
- Maharashtra (9 per cent)
- Remaining 5 per cent resources are in Haryana, Tamil Nadu, Uttarakhand and West Bengal
- Domestic requirements are met by imports.

Pyrites

- Pyrite is a **sulphide of iron**.
- Chief source of **sulphur**.
- High proportion of sulphur is injurious to iron. Hence is it removed and used to produce sulphur.
- Sulphur is very useful for making sulphuric acid which in turn is used in several industries such as fertilizer, chemicals, rayon, petroleum, steel, etc.
- Elemental sulphur is useful for manufacturing explosives, matches, insecticides, fungicides and for vulcanizing rubber
- Pyrites occur in Son Valley in Bihar, in Chitradurga and Uttar Kannada districts

of Karnataka and the pyritous coal and shale of Assam coalfields.

- It is widely distributed and scattered across the country.

Gold – Silver Distribution – India & World. Gold Reserves in India. Gold Distribution Across the World. Silver Distribution – India & World.

Gold Reserves in India

- Gold usually occurs in auriferous [(of rocks or minerals) containing gold] rocks.
- It is also found in sands of several rivers.
- Gold is also known as international currency.

Resources in terms of the metal ore (primary) are located in

1. Bihar (45 per cent)
2. Rajasthan (23 per cent)
3. Karnataka (22 per cent)
4. West Bengal (3 per cent)
5. Andhra Pradesh and Madhya Pradesh (2 per cent each).

Resources in terms of metal content

1. Karnataka,
2. Rajasthan,
3. Bihar, Andhra Pradesh, Jharkhand, etc.

- **Kolar Gold Field**, **Hutti Gold Field** and **Ramgiri Gold** Field are the most important gold fields.

Karnataka

- Karnataka is the largest producer of gold in India.
- Gold mines are located in Kolar [Kolar Gold Field], Dharwad, Hassan and Raichur [Hutti Gold Field] districts.
- Kolar Gold Fields is one of the deepest mines of the world. [Usually, gold mines are the deepest mines in the world. **Mponeng Gold Mine** in South Africa is the deepest mine in the world (3.9 km deep)]
- Hutti mines are exploited to their maximum levels and the ore left behind is of very low grade. The mining has almost ceased due to little or no profitability.
- The Kolar Gold Field has also run out of quality reserves and is on the verge of closure.

Andhra Pradesh

- Second largest producer of gold in India.
- Ramagiri in Anantapur district is the most important gold field in AP.
- Alluvial Gold [gold scattered in silt] and Placer deposits [gold bearing rocks] in small quantity are widely spread in a large number of rivers

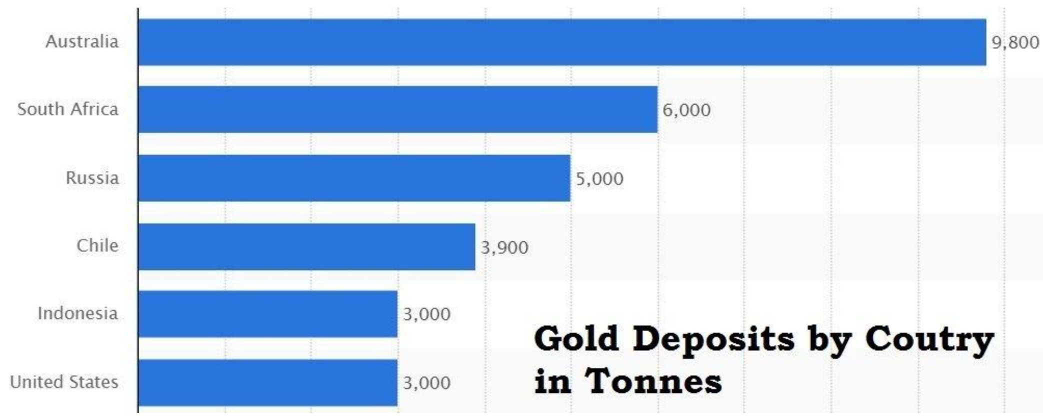
Jharkhand

- Sands of the Subarnarekha (gold streak) river have some alluvial gold.
- Sona nadi in Singhbhum district is important.
- Sonapat valley is another major site with alluvial gold.

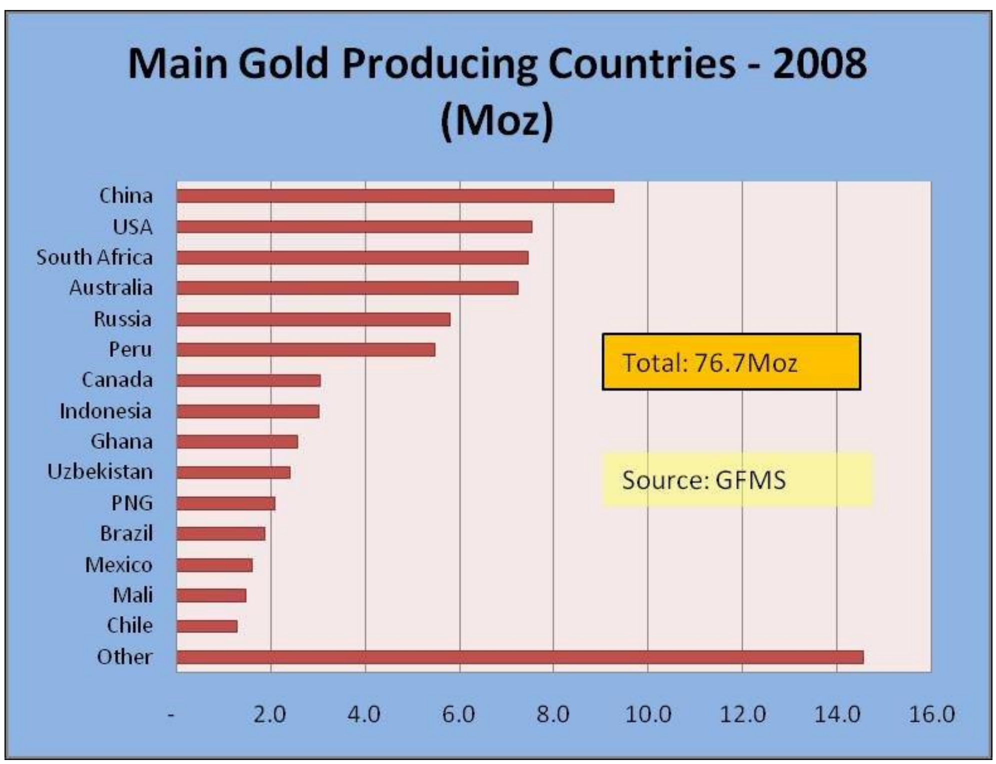
Kerala

- The river terraces along the Punna Puzha and the Chabiyar Puzha have some alluvial gold.

Gold Distribution Across the World



- Countries with significant deposits: South Africa, Australia, Indonesia, Canada,



Ghana, Chile, China, USA, Russia etc.

Countries with highest gold deposits

Major Gold Producing Countries

Silver Distribution – India & World

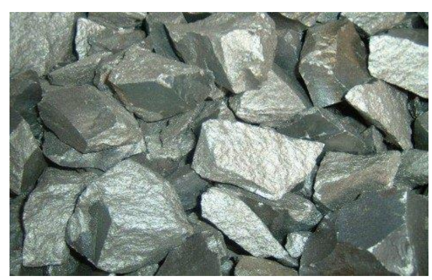
COUNTRIES	PRODUCTION (in metric tonnes)	COUNTRIES	PRODUCTION (in metric tonnes)
Peru	4,000	Bolivia	1,360
Mexico	3,500	United States	1,280
China	3,000	Poland	1,200
Australia	1,700	Canada	700
Chile	1,500	Other countries	2,600
Russia	1,400		

SOURCE: USGS: Mineral Commodity Summary 2017

- Used in chemicals, **electroplating**, **photography** and for **colouring glass**, etc.
- The chief ore minerals of silver are agentine, stephanite, pyrargyrite and proustite.
- It is found mixed with several other metals such as copper, lead, gold, zinc, etc.
- India is not a major producer of silver in the world.
- **Zawar mines** in **Udaipur district** of Rajasthan is the major producer of silver [smelting of galena ore in Hindustan Zinc Smelter].
- The Tundoo Lead Smelter in Dhanbad district of Jharkhand is another major silver producer.
- Some silver is produced by Kolar Gold Fields and Hutti gold mines.
- The Hindustan Copper Ltd. at Maubhandar smelter in Singhbhum district of Jhakhand obtains silver from copper slimes.
- Silver is also produced by Vizag Zinc smelter in Andhra Pradesh from the lead concentrates.
- Manganese – Distribution of Manganese in India, State wise reserves of Manganese, World Distribution of Manganese.

Manganese

- Manganese is not found as a free element in nature.
- It is often found in combination with iron.
- The most important manganese ore is **pyrolusite.**
- Manganese is primarily used in iron and steel industry.
- It is the basic raw material for manufacturing steel alloys.
- 6 kilograms of manganese is required for manufacturing one tonne of steel.
- Manganese is also used in the manufacturing of bleaching powder, insecticides, paints, and batteries.



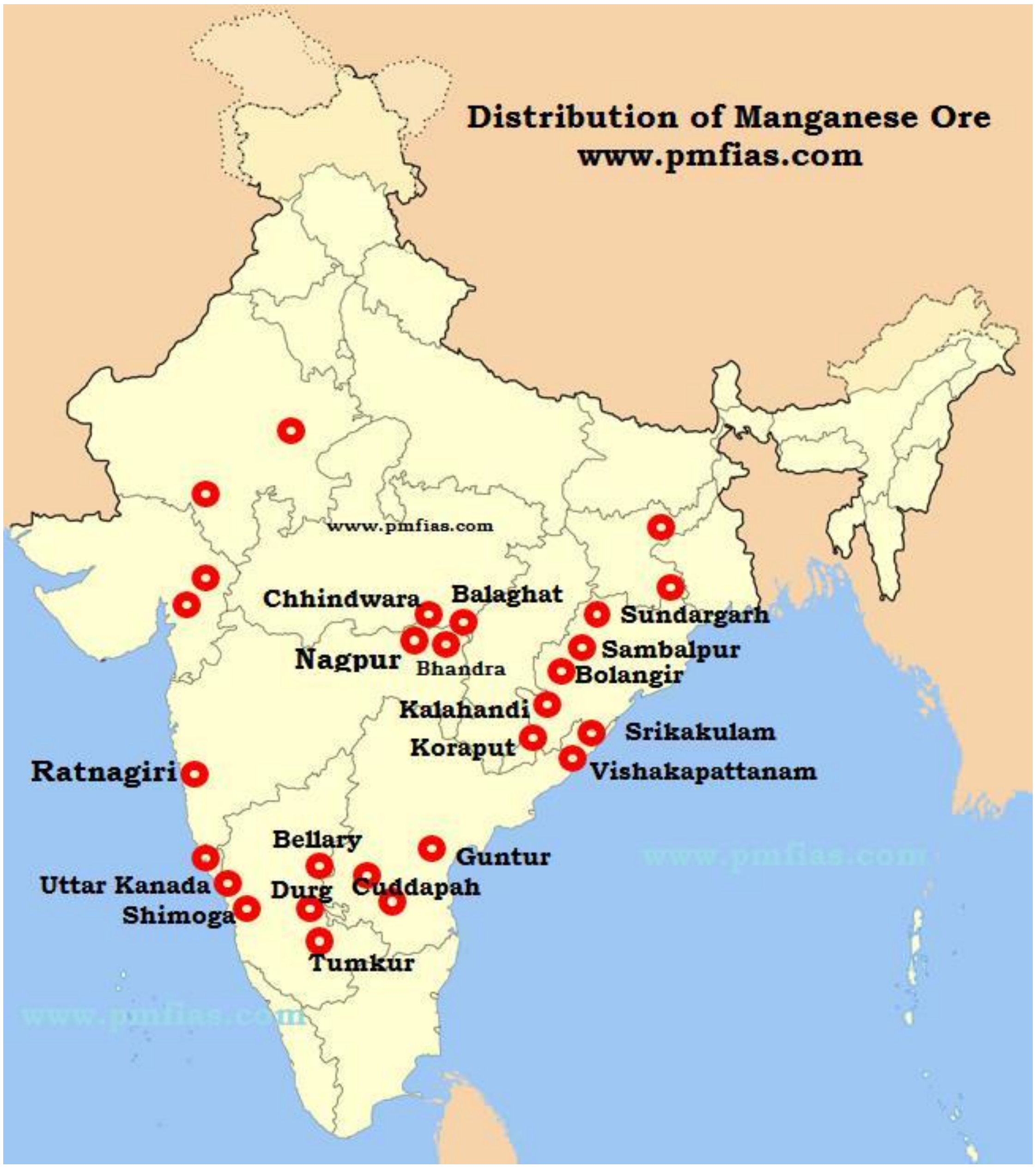
Manganese Ore Distribution in India

- India processes **second** largest reserves in the world after **Zimbabwe**; 430 million tonnes
- India is the world's **fifth largest producer** of manganese ore after China, Gabon, South Africa and Australia.

- *Maharashtra, Madhya Pradesh, Odisha, Andhra Pradesh* and *Karnataka* are the major manganese producing states.
- **Maharashtra** and **Madhya Pradesh** together produce more than half of India's manganese

State wise reserves of Manganese

- **Odisha (44%)**,
- Karnataka (22%),
- Madhya Pradesh (13%),
- Maharashtra (8%),
- Andhra Pradesh (4%)
- Jharkhand and Goa (3% each),
- Rajasthan, Gujarat and West Bengal (remaining 3 per cent).



Maharashtra

- Produces about 27.66 per cent of Indian manganese.
- The main belt is in Nagpur and Bhandara districts.
- High grade ore is found in Ratnagiri district also.

Madhya Pradesh

- Produces about 27.59 per cent of India's manganese ore.

- The main belt extends in Balaghat and Chhindwara districts.
- It is just an extension of the Nagpur Bhandara belt of Maharashtra.

Odisha

- 24 per cent production. [1st in reserves but 3rd in prduction]
- **Gondite** [regional names] deposits occur in Sundargarh district and **Kodurite** and **Khondolite** deposits in Kalahandi and Koraput Districts.
- Manganese is also mined from the lateritic deposits in Bolangir and Sambalpur districts

Andhra Pradesh

- 13% of India's manganese production.
- Srikakulam and Vishakhapatnam districts.
- Srikakulam district has the distinction of being the earliest producer (1892) of manganese ore in India.
- Cuddapah, Vijayanagaram and Guntur are other manganese producing districts.

Karnataka

- 6 per cent of India's manganese.
- Uttara Kannada, Shimoga, Bellary, Chitradurg and Tumkur districts.

Other producers

- Goa,
- Panchmahals and Vadodara in Gujarat,
- Udaipur and Banswara in Rajasthan and
- Singhbhum and Dhanbad districts in Jharkhand are other producers of manganese.

Export of Manganese

- Four-fifths of the total production is consumed domestically.
- Exports constantly decreasing due to increasing domestic demand.
- Japan is the largest buyer of Indian manganese.
- The other buyers are the USA, UK, Germany, France, Norway.

World Manganese Ore Distribution

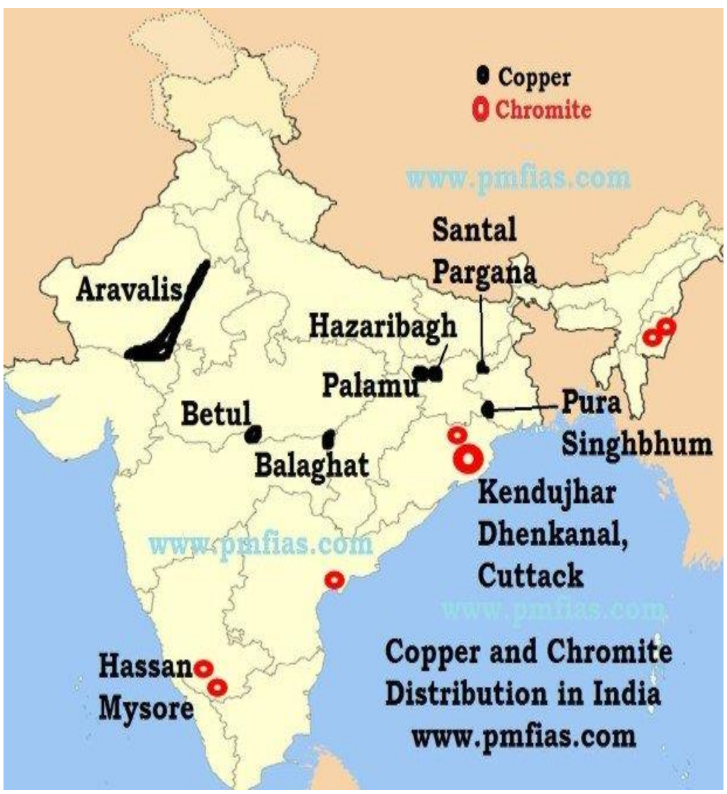
Chromite Ore Distribution In India and World. Copper Reserves in India and World.

Chromite

- Chromite is an oxide of iron and chromium = Combination of chromium, iron and oxygen.
- It is the only economic ore of chromium.
- The chromium extracted from chromite is used in **chrome plating** and alloying for production of **corrosion resistant** super alloys, nichrome, and **stainless steel**.
- Used in many other metallurgical, refractories and chemical industries.

Chromite Ore Distribution In India

- Reserves of chromite in India is estimated at 203 MT.
- **93 per cent** of the resources are in **ODISHA** [**Sukinda valley in Cuttack and Jajapur**]
- Minor deposits are spread over Manipur, Nagaland, Karnataka, Jharkhand, Maharashtra, TN & AP.



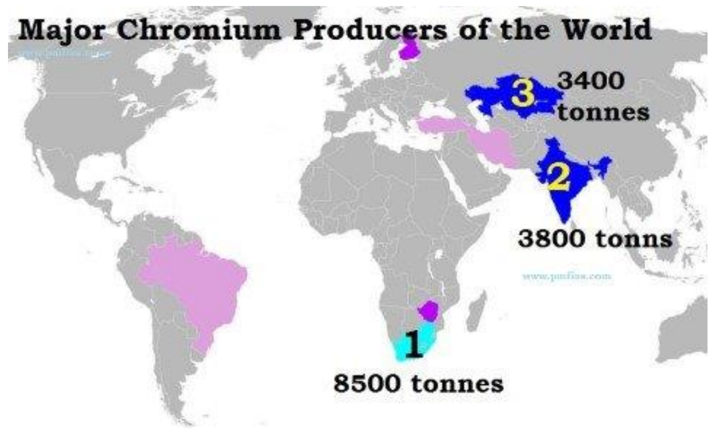
Chromite in Odisha

- Odisha is the sole producer [99 per cent] of chromite ore.
- Over 85 per cent of the ore is of **high grade** [Keonjhar, Cuttack and Dhenkanal].

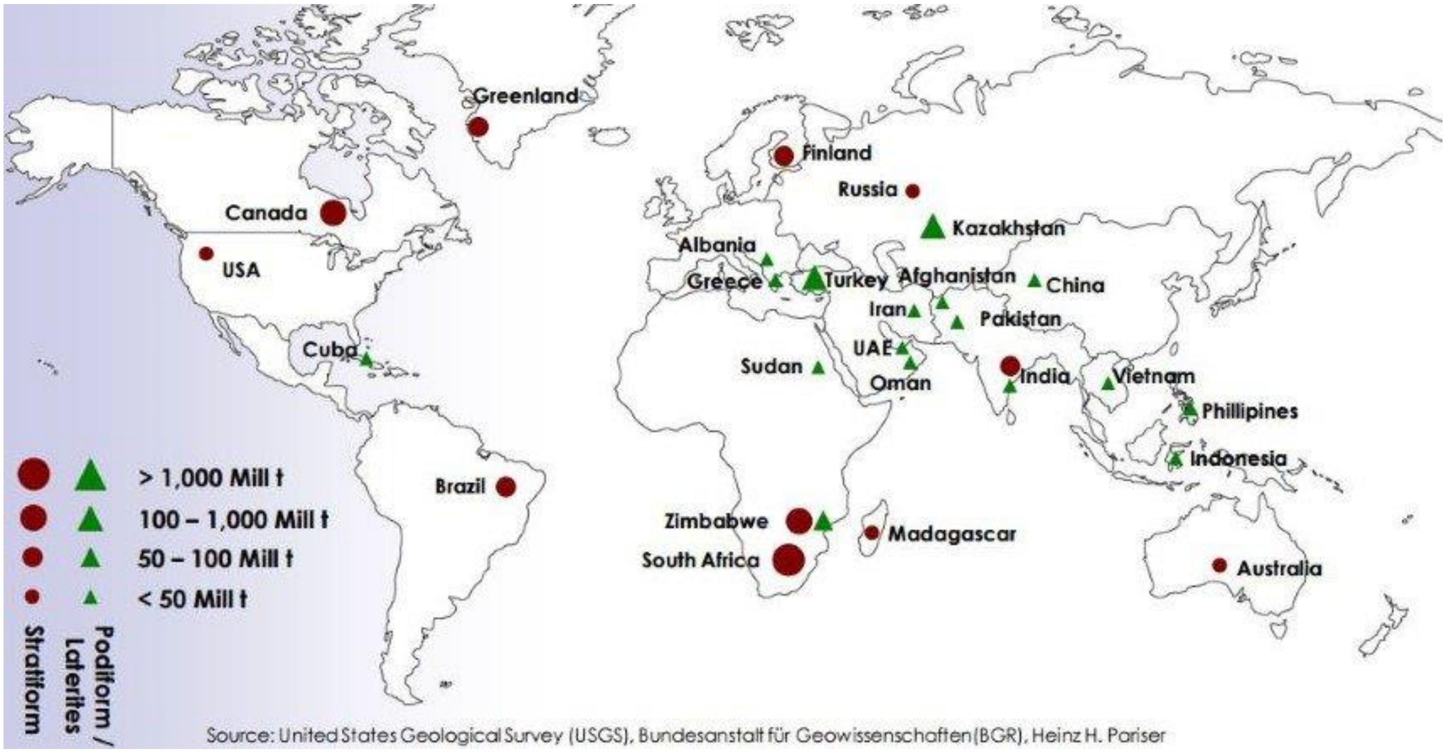
Chromite in Other States

- **Karnataka** is the second largest producer.
- The main production comes from Mysore and Hassan districts.
- Krishna district of Andhra Pradesh, Tamenglong and Ukhrul districts of Manipur are other producers.

Chromite Ore Distribution Across the World



	Reserve Base		
	in Mill t	in %	Rank
South Africa	6,860	74.4	1
Zimbabwe	930	10.1	2
Kazakhstan	387	4.2	3
Turkey	220	2.4	4
Finland	120	1.3	5
India	54	0.6	6



http://www.boldventuresinc.com/news_pdf/uploaded/2013-Mar3-PDAC-Pariser-Chrome-Presentation.pdf

Copper

- Copper is a good conductor of electricity and is ductile [able to be drawn out into a thin wire].
- It is an important metal used by automobile and defense industries.
- Alloyed with **iron** and **nickel** to make **stainless steel**.
- Alloyed with nickel to make **'morel metal'**.
- Alloyed with aluminium to make **'duralumin'**.
- When alloyed with zinc it is known as **'brass'** and with tin as **'bronze'**.

Iron + Nickel + Copper + Chromite +.....== Stainless Steel.

Copper + Nickel == Morel Metal.

Copper + Aluminium == Duralumin.

Copper + Zinc == Brass.

Copper + Tin == Bronze.

- Copper ore is found in ancient as well as in younger rock formations and occurs as veins and as bedded deposits
- Mining for copper is **costly and tedious affair** because most of the copper ores contain a small percentage of the metal.
- India has **low grade copper ore** [less than 1% metal content][international average 2.5%]
- The major part of supply comes from the USA, Canada, Zimbabwe, Japan and Mexico.

Copper Reserves in India

- 1558.46 million tonnes.
- **Rajasthan (50%)**
- **Madhya Pradesh (24%)**
- Jharkhand (19%)
- The rest 7 per cent in AP, Gujarat, Haryana, Karnataka etc.

Madhya Pradesh

- 1st in production [59.85 %].
- Malanjkhand copper mines of Balaghat district are the most important ones.
- Reserves of moderate size are also found in Betul district.

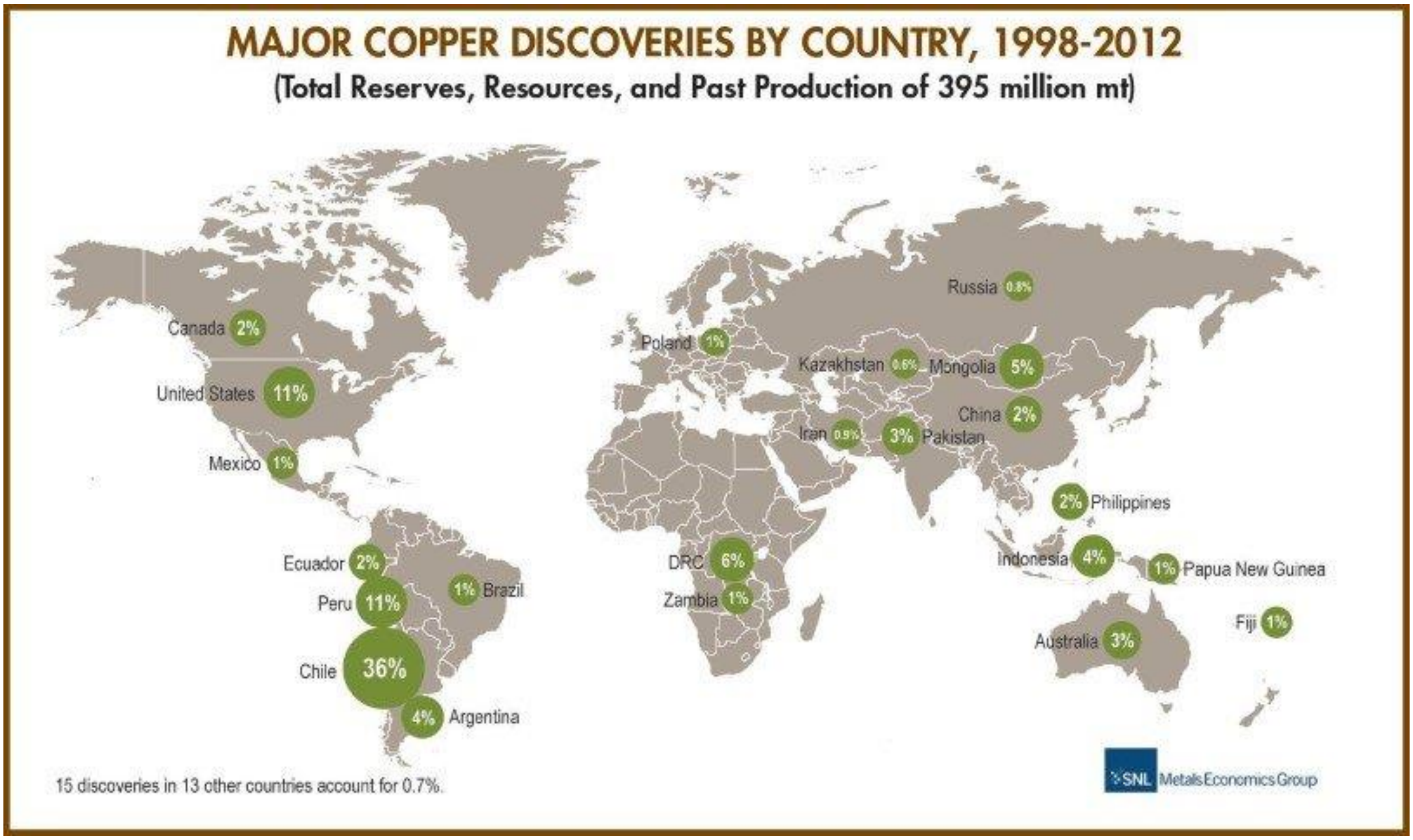
Rajasthan

- 2nd in production [28%]
- Found along the **Aravali range.**
- Ajmer, Alwar, Bhilwara, Chittaurgarh, Dungarpur, Jaipur, Jhunjhunu, Pali, Sikar, Sirohi and Udaipur districts.
- Khetri-Singhana belt in Jhunjhunu district is the most important copper producing area.

Jharkhand

- 3rd in production [11 %].
- **Singhbhum** is the most important copper producing district.
- Found in Hazaribagh district, Santhal Parganas and Palamu districts.

Major Copper Reserves Across the World



Nickel

- Nickel does not occur free in nature.
- It is found in association with copper, uranium and other metals.
- Important alloying material.

Iron + Nickel == stainless steel.

- It is hard and has great **tensile strength.**
- Hence nickel steel is used for manufacturing **armoured plates, bullet jackets** etc.
- Nickel + Copper or Silver == Coins.
- Nickel-aluminium alloys are used for **manufacturing aeroplanes** and **internal combustion engines.**
- Metallic nickel is used for making storage batteries and as a catalyst for **hydrogenation or hardening of fats and oils** intended for use in soap and foodstuffs and in making vanaspati.
- Important occurrences of **nickeliferous limonite** are found in the **Sukinda valley of Jajapur district, Odisha.** Here it occurs as oxide.
- Nickel also occurs in sulphide form along with copper mineralization in east Sighbhum district, Jharkhand.
- In addition, it is found associated with uranium deposits at Jaduguda, Jharkhand.

- Other important occurrences of nickel are in Karnataka, Kerala and Rajasthan.
- Polymetallic sea nodules are another source of nickel.
- About 92 per cent resources are in Odisha.
- The remaining 8 per cent resources are distributed in Jharkhand, Nagaland and Karnataka

Denomination	Picture	Metal	Weight (gms)	Diameter (mm)	Shape
Five rupee (new)		Ferritic Stainless Steel (FSS)	6.00	23	Circular
Five rupee (old)		Cupro-Nickel	9.00	23	Circular
Two rupee (new)		Ferritic Stainless Steel (FSS)	5.62	27	Circular
Two rupee (old)		Cupro-Nickel	6.00	26	Eleven Sided
One rupee		Ferritic Stainless Steel (FSS)	4.85	25	Circular
Fifty paise		Ferritic Stainless Steel (FSS)	3.79	22	Circular
Twenty five paise		Ferritic Stainless Steel (FSS)	2.83	19	Circular

Graphite – Applications of Graphite, Major Producers of Graphite – India & World. Diamonds – Diamonds in India, Diamonds Across the World. Differences between Diamond and Graphite.

Graphite

- Graphite is a naturally-occurring form of crystalline carbon.
- It is also known as **plumbago** or **black lead**.
- The carbon content in Graphite is never less than 95%.
- Graphite may be considered the highest grade of coal, just above anthracite.

Carbon content in **Peat < Lignite < Bituminous < Anthracite < Graphite < Diamond**

- It is not normally used as fuel because it is difficult to ignite.
- It is found in **metamorphic** and igneous rocks.
- Graphite is extremely soft, cleaves [splits into layers] with very light pressure.
- It is extremely resistant to heat and is highly unreactive.
- Most of the graphite is formed at **convergent plate boundaries** where organic-rich shales and limestones were subjected to **metamorphism** due to heat and pressure.
- Metamorphism produces marble, schist and gneiss that contains tiny crystals and flakes of graphite.
- Some graphite forms from the metamorphism of coal seams. This graphite is known as "**amorphous graphite**".
- **Graphite is a non-metal and it is the only non-metal that can conduct electricity.**

Applications of Graphite

- Natural graphite is mostly consumed for refractories, batteries, steelmaking, expanded graphite, lubricants etc.
- A refractory material is one that retains its strength at high temperatures.
- Natural and synthetic graphite are used to construct the anode of all major battery technologies
- The lithium-ion battery utilizes roughly twice the amount of graphite than lithium carbonate.
- Natural graphite in this end use mostly goes into carbon raising in molten steel. [to make steel stronger]
- Natural amorphous graphite are used in brake linings for heavier vehicles, and became important with the need to substitute for asbestos.

- Graphite lubricants are specialty items for use at very high or very low temperatures.
- Modern pencil lead is most commonly a mix of powdered graphite and clay.

Major Producers of Graphite – India & World

- India is a major global producer of flake graphite.

Total Indian Graphite Resources

1. Arunachal Pradesh (43%),
2. Jammu & Kashmir (37%),
3. Jharkhand (6%),
4. Tamil Nadu (5%) and
5. Odisha (3%)

Operational Indian Graphite Resources

Most of the Graphite Production is concentrated in these states

- **Tamil Nadu (37%),**
- **Jharkhand (30%), [Palamu district in Jharkhand is the most important]**
- **Odisha (29%).**

Graphite Production Across the World

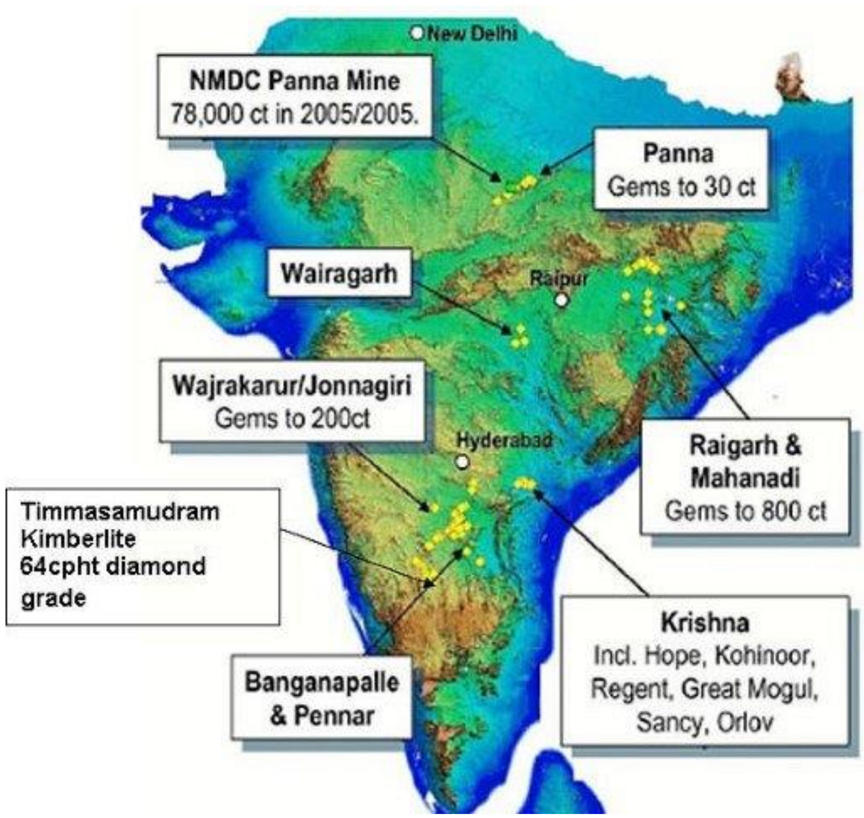
1. China (more than 50%)
2. India (20%)
3. Brazil.

COUNTRIES	PRODUCTION (in '000 metric tonnes)	COUNTRIES	PRODUCTION (in '000 metric tonnes)
China	780	Mexico	8
India	170	Ukraine	6
Brazil	80	Zimbabwe	6
Canada	30	Madagascar	5
North Korea	30	Sri Lanka	4
Turkey	30	Norway	2
Russia	14	Other Countries	1

- Graphite is not mined in the United States. U.S. substitutes graphite with synthetic graphite.

Diamonds

- Diamond is the hardest naturally occurring substance found on Earth.
- Diamonds are formed in mantle. They brought to the earth's crust due to **volcanism**. Most of the diamonds occur in dykes, sill etc. [**Volcanic Landforms**].
- Diamond is the Diamonds are used in ornaments, polishing the surfaces of metals and in gem cutting.
- The most important industrial use of diamonds is in cutting-edges of drills used



for exploration and mining of minerals [Diamond is the hardest substance and it can break other substances without itself getting broken].

Diamonds in India

- The **Vindhayan system** have diamond bearing regions from which Panna and Golconda diamonds have been mined.

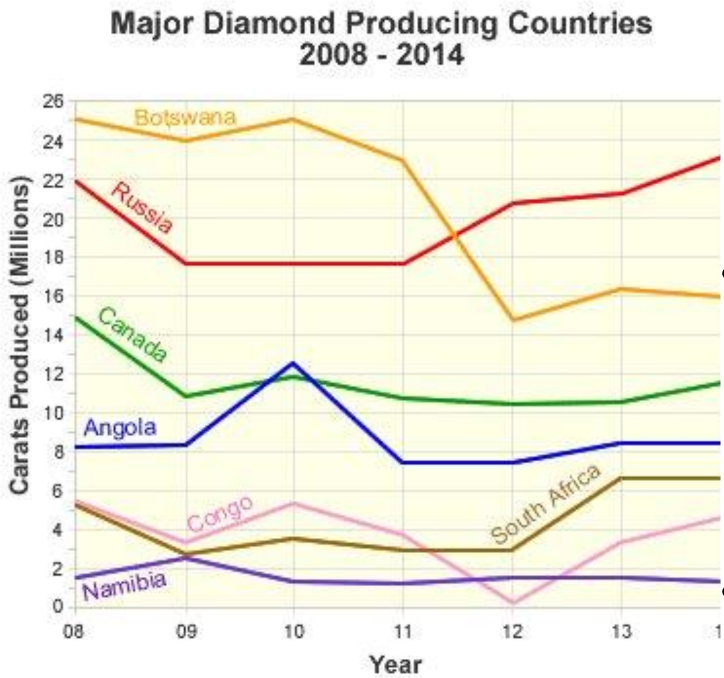
1. Panna belt in Madhya Pradesh;
2. Wajrakarur Kimberlite pipe in Anantapur district and
3. Gravels of the Krishna river basin in Andhra Pradesh.

- Reserves have been estimated only in Panna belt and Krishna Gravels in Andhra Pradesh.

- The new kimberlite fields are discovered recently in Raichur-Gulbarga districts of Karnataka.
- Reserves of diamonds in India are not yet exhausted and modern methods are being applied for intensive prospecting and mining.
- Cutting and polishing of diamonds is done by modem techniques at important centres like Surat, Navasari, Ahmedabad, Palampur etc.

Diamonds Across the World

- The leading producers of natural diamond are Russia, Botswana, Canada, Australia, South Africa, Russia and Zaire [Congo].
- Other important producers include Namibia, Ivory Coast, Sierra Leone, Venezuela, Brazil etc.
- US is the largest producer of synthetic industrial diamonds
- Russia holds what is believed to be the world's largest and richest diamond resources.
- **Botswana is the leading diamond-producing country** in terms of value, and the second largest in terms of volume. The two important ones are Orapa and Jwaneng, two of the most prolific diamond mines in the world.
- Botswana's resources produce the full range of diamonds, in all sizes, colors and clarities.
- Democratic Republic of Congo (DRC) is also one of the Africa's largest diamond producer.
- Australia is the leading producer of color diamonds. Australia is famous for its pink, purple and red diamonds.
- South Africa has the most diverse range of diamond deposits in the world. Deposits include open pit and underground kimberlite pipe/dyke/fissure mining.



Pic From: http://geology.com/articles/gem-diamond-map/

Differences Between Graphite and Diamond

- Graphite and Diamond are the major allotropes of carbon. Other important allotrope being anthracite coal.

[Allotrope → Each of two or more different physical forms in which an element can exist (e.g. graphite, charcoal, and diamond as forms of carbon).]

- Graphite and diamond share the same composition but have very different structures.

Graphite	Diamond
Graphite contains 95% or more carbon.	Diamond is 100% carbon.
Graphite is a non-metallic mineral that forms when carbon is subjected to extreme heat and pressure in **Earth's crust** and in the upper mantle.	Diamond is also a non-metallic mineral that forms when carbon is subjected to extreme heat and pressure in the **mantle.**
Graphite is one of the most stable substances on earth.	Diamond (one of the most stable) is less stable than graphite.
The carbon atoms in graphite are linked in a hexagonal network that forms sheets that are one atom thick. These sheets are poorly connected and easily cleave or slide over one another if subjected to a small amount of force. This gives graphite it's very low hardness, its perfect cleavage and its slippery feel. [Pencil Lead is not made of lead as we normally beleive. It is made of graphite. You know why?]	In contrast, the carbon atoms in diamond are linked into a frameworks structure. Every carbon atom is linked into a three dimensional network with strong covalent bonds. This arrangement holds the atoms firmly in place and make diamond an exceptionally hard material.

http://geology.com/minerals/graphite.shtml

https://en.wikipedia.org/wiki/Graphite

http://ibm.nic.in/writereaddata/files/01192015114812IMYB_2013_Vol%20III_Graphite%202013.pdf

http://www.indmin.com/Article/3404526/The-Indian-graphite-industry-why-we-need-to-take-notice.html?ArticleId=3404526

Non-Metallic Mineral Distribution in India – Mica, Limestone, Dolomite, Asbestos, Magnesite, Kyanite, Sillimanite and Gypsum.

Mica

- Mica is a naturally occurring non-metallic mineral that is based on a collection of **silicates**.

- Mica is a very good insulator that has a wide range of applications in electrical and electronics industry.
- It can withstand high voltage and has low power loss factor.
- It is used in toothpaste and cosmetics because of its glittery appearance. It also acts as a mild abrasive in toothpaste.
- **India** is one of the foremost suppliers of mica to the world. Mica-bearing igneous rocks occur in AP, Bihar, Jharkhand, Maharashtra, Rajasthan.

Mica Reserves in India

1. **Andhra Pradesh (41 per cent)**
2. **Rajasthan (21 per cent)**
3. **Odisha (20 per cent)**
4. Maharashtra (15 per cent)
5. Bihar (2 per cent)
6. Jharkhand (Less than 1 per cent)

Mica Distribution and Production in India

- India has a near **monopoly** in the production of mica [60 % of world's total].
- Production decreased in recent times due to fall in demand in the international market. Fall in demand is due to better synthetic alternatives that are available.

Andhra Pradesh

- 1st in production [93 %].
- The mica belt lies in **Nellore district** [Gudur Mica mines].
- Vishakhapatnam, West Godavari and Krishna are other important mica producing districts.

Rajasthan

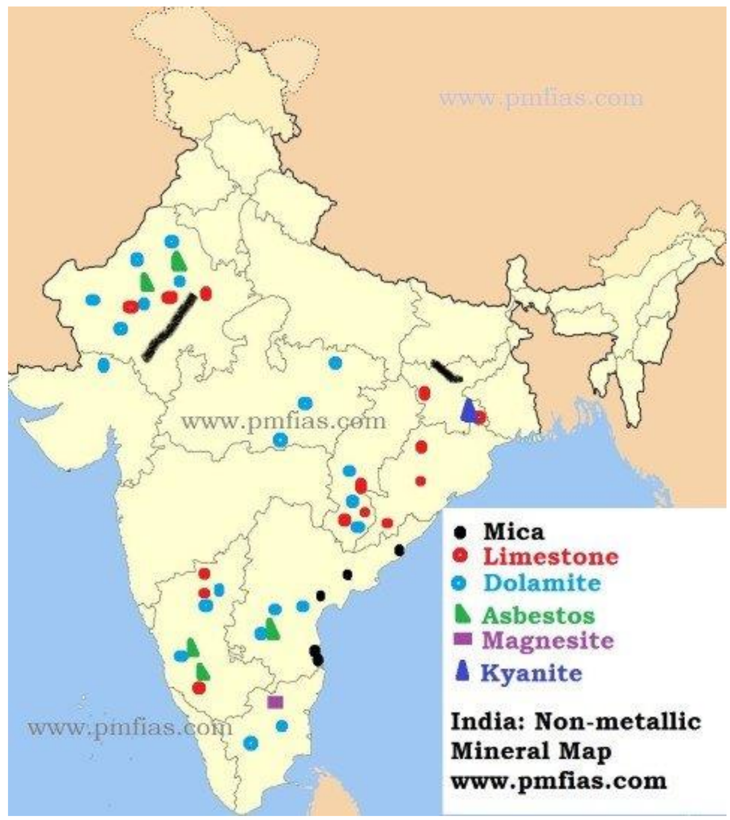
- 2nd in production [6.3 %].
- The main mica belt extends from Jaipur to Udaipur [Along Aravalis].

Jharkhand

- 3rd in production.
- Mica is found in a belt extending for about 150 km in length and 32 km in width from Gaya district of Bihar to Hazaribagh and Koderma districts of Jharkhand. This belt contains the richest deposits of high quality **ruby mica**.
- Koderma is a well-known place for mica production in Jharkhand.

Mica Exports

- India is the largest exporter of mica.
- Certain grades of Indian mica are and will remain vital to the world's electrical industries.
- Major exports are carried out through Kolkata and Vishakhapatnam ports.
- Important imports of Indian mica are Japan (19%), the USA (17%), U.K, etc.



Limestone

- Limestone rocks are composed of either calcium carbonate, the double carbonate of calcium and magnesium, or mixture of both.
- Limestone also contains small quantities of silica, alumina, iron oxides, phosphorus and sulphur.
- Limestone deposits are of sedimentary origin and exist in all the geological

sequences from Pre-Cambrian to Recent **except in Gondwana**.

- 75 per cent Limestone is used in **cement industry**, 16 per cent in **iron and steel industry** [It acts as flux] and 4 per cent in the chemical industries.
- Rest of the limestone is used in paper, sugar, fertilizers, etc.
- Almost all the states of India produce some quantity of limestone.
- Over three-fourths of the total limestone of India is produced by Madhya Pradesh, Rajasthan, Andhra Pradesh, Gujarat, Chhattisgarh and Tamil Nadu.

Madhya Pradesh

- Madhya Pradesh is the largest producer of limestone [16 per cent].
- Large deposits occur in the districts of Jabalpur, Satna, Betul, etc.

Rajasthan

- Rajasthan has about 6 per cent of the reserves and produces over 16 per cent of the total limestone of India. Production occurs in almost all districts.

Andhra Pradesh

- Andhra Pradesh possesses about one-third of the total reserves of the cement grade limestone in the country.
- Extensive deposits occur in Cuddapah, Kumool, Guntur, etc.

Gujarat

- Gujarat produces only about 11 per cent of the total limestone of India.
- High grade limestone deposits occur in Banaskantha district.

Chhattisgarh

- Chhattisgarh accounts for more than nine per cent of total limestone of India .Deposits of limestone occur in Bastar, Durg and surrounding districts.

Tamil Nadu

- Large scale reserves in Ramnathapuram, Tirunelveli, Salem, Coimbatore and Madurai districts.

Karnataka

- Gulbarga, Bijapur and Shimoga districts.

Dolomite

- **Limestone with more than 10 per cent of magnesium is called dolomite**.
- When the percentage rises to 45, it is true dolomite.
- Dolomite is mainly used as blast furnace flux, as a source of magnesium salts and in fertilizer and glass industries.
- Iron and Steel industry is the chief consumer of dolomite [90 per cent] followed by fertilizer, ferro-alloys and glass.
- Dolomite is widely distributed in the all parts of the country.
- Orissa, Chhattisgarh, Andhra Pradesh, Jharkhand, Rajasthan and Karnataka are the main producing states and contribute more than 90 per cent of the total production.
- **Orissa** and **Chhattisgarh** together account for about 57 per cent dolomite of India.

Orissa

- Orissa is the largest pro-ducer of dolomite [29 per cent].
- The main deposits occur in Sundargarh, Sambalpur and Koraput districts.

Chhattisgarh

- Closely following Orissa is the state of Chhattisgarh which produces about 28 per cent dolomite of India.
- The main deposits occur in Bastar, Bilaspur, Durg and Raigarh districts.

Jharkhand

- Dolomite occurs in bands to the north of Chaibasa in Singhbhum district and Palamu district.

Rajasthan

- Ajmer, Alwar, Bhilwara, Jaipur, Jaisalmer etc. are the main producing districts.

Karnataka

- Belgaum, Bijapur, Chitradurga, Mysore, etc.

Asbestos

- Two quite different minerals are included under this name; one, a variety of **amphibole**, and the other, more important, a **fibrous variety of serpentine** (**chrysotile**).
- Chrysotile is more important variety and accounts for 80 per cent of the asbestos of commercial use.
- Asbestos has great commercial value due to its fibrous structure, filaments of high tensile strength and its **great resistance to fire**.
- It is widely used for making **fire-proof** cloth, rope, paper, millboard, sheeting, etc.
- It is also used in making aprons , gloves, brake-linings in automobiles etc.
- Asbestos cement products like sheets, pipes and tiles are used for building purposes.
- When asbestos is brittle, it is made into filter pads for filtering acids.
- Mixed with magnesia, it is used for making 'magnesia bricks' used for heat insulation.
- Two states of **Rajasthan and Andhra Pradesh** produce almost the whole of asbestos of India.
- Rajasthan is the largest producer. Important occurrences are known in Udaipur, Dungarpur, Alwar, Ajmer and Pali districts.
- In Andhra Pradesh, asbestos of fine quality occurs in Pulivendla taluk of Cuddapah district.
- In Karnataka, the main deposits occur in Hassan, Mandya, Shimoga, Mysore and Chikmaglur districts.

Magnesite

- It is an alteration product of dunites (peridotite) and other basic magnesian rocks.
- It is primarily used for manufacturing refractory bricks.
- It is also used as a bond in abrasives, manufacture of special type of cement for artificial stone, tiles and for extraction of the metal magnesium.
- Steel industry also uses magnesite.
- Major deposits of magnesite are found in **Uttaranchal, Tamil Nadu and Rajasthan**.
- **Tamil Nadu** is the largest producer [three-fourth] of magnesite in India.
- Tamil Nadu has one of the largest deposits of magnesite in the world and the largest in India are found at **Chalk Hills** near Salem town.

Kyanite

- Kyanite occurs in metamorphic aluminous rocks.
- It is primarily used in metallurgical, ceramic, refractory, glass, cement industries due to its **ability to stand high temperatures**.
- It is also used in making **sparking plugs** in automobiles.
- **India has the largest deposits of kyanite** in the world. All the three grades of kyanite are found here. Kyanite grades depend on aluminium content. Greater the aluminium content, greater the quality.
- Jharkhand, Maharashtra and Karnataka produce practically the whole of kyanite of India.

Jharkhand

- Jharkhand is the largest producer of kyanite [four-fifths].
- Ores with high degree of purity with percentages of aluminium silicate reaching 95 to 97 are found in the Singhbhum district.

Maharashtra

- Maharashtra [second highest producer of kyanite] produced 14.5 per cent of the total kyanite in 2002-03.
- Most of the reserves are in Bhandara district.

Karnataka

- Karnataka is the third largest producer [5.6 per cent in 2002-03].
- Commercially, workable deposits occur in Hassan district.

Sillimanite

- The occurrence and uses of sillimanite are almost the same as those of kyanite.
- The main concentration of Sillimanite is found in Tamil Nadu, Orissa, Kerala, Andhra Pradesh and West Bengal.
- Orissa is the largest producer of sillimanite in India. Ganjam district is an important sillimanite producing district.
- Kerala is the second largest producing state. The beach sands of Kerala contain 5 to 6 per cent of sillimanite.

Gypsum

- Gypsum is a hydrated sulphate of calcium.
- It is a white opaque or transparent mineral.
- It occurs in sedimentary formations such as limestones, sandstones and shales.
- It is mainly used in making ammonia sulphate fertilizer and in cement industry.
- It makes upto 4-5 per cent of cement.
- It is also used in making plaster of Paris, moulds in ceramic industry, tiles, plastics, etc.
- It is applied as surface plaster in agriculture for conserving moisture in the soil and for aiding nitrogen absorption.
- Rajasthan is by far the largest producer of gypsum in India [99 per cent of the total production of India].
- The main deposits occur in the Tertiary clays and shales of Jodhpur, Nagaur and Bikaner. Jaisalmer, Barmer, Chum, Pali and Ganganagar also have some gypsum bearing rocks.
- The remaining gypsum is produced by Tamil Nadu [Tiruchirapalli district], Jammu and Kashmir, Gujarat and Uttar Pradesh in order of production.
- Water and phosphoric acid plants are important sources of by product gypsum.
- Marine gypsum is recovered from salt pans during the processing for common salt in Gujarat and Tamil Nadu.
- Phospho-gypsum is obtained as a byproduct while manufacturing phosphoric acid whereas fluro-gypsum is obtained while manufacturing aluminium flouride and hydro-fluoric acid.
- The recovery of by-product phospho-gypsum, fluoro- gypsum, and marine gypsum together is higher than mineral gypsum.

Salt

- Salt is obtained from sea water, brine springs [salt water springs], wells and salt pans in lakes and from rocks.
- Rock salt is taken out in Mandi district of Himachal Pradesh and in Gujarat. It is less than 1 per cent of the total salt produced in India.
- Sambhar Lake in Rajasthan produces about 10 per cent of our annual production.
- Sea brine is the source of salt in Gujarat, Maharashtra and Tamil Nadu.
- Gujarat coast produces nearly half of our salt.

Conservation of Mineral Resources

- Mining is often called the **robber industry** because of its exploitative nature.
- Mining should be made efficient with better mining and benefication technologies.
- A clear roadmap has to be carved for the better management of mineral resources for decades. Stringent laws to prevent the plundering of minerals is the need of the hour.

- Transparency must be the priority in extraction of mineral resources. Corrupt practices have led to mismanagement of mineral resources making mining industry highly inefficient.
- Recycling of cyclic minerals [iron, aluminium, copper, brass, tin] can help in reducing the waste.
- Scarce and expensive minerals must be substituted with the abundant ones. Example: Aluminium substitutes copper in electrical industry.
- Instead of exporting minerals, India should focus on exporting goods manufactured using these minerals. This would create more jobs locally.
- Innovation and research into synthetic minerals is essential.

Nuclear Fission – Nuclear Reactor: Nuclear Reactor Coolant, Moderator, Control Rods Criticality etc. Types of Nuclear Reactors: Light-water reactor (LWR) and Pressurized Heavy-Water Reactor (PHWR) and more.

Prelims: General Science

Mains: Science and technology – developments and their applications and effects in everyday life. [Nuclear Energy and related concepts are all evergreen]

Nuclear fission

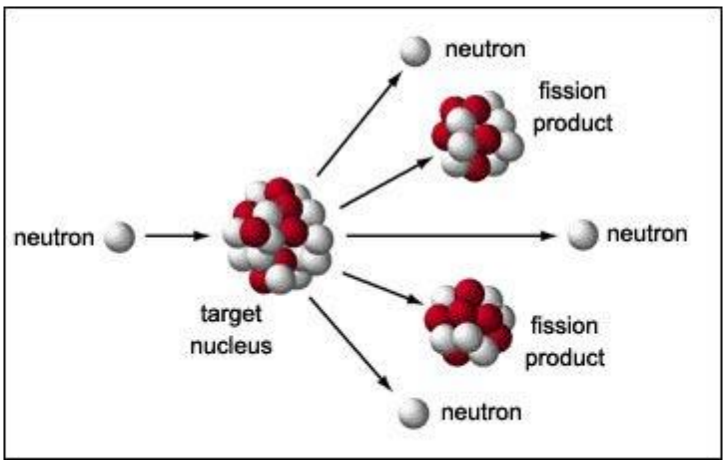
- The discovery of nuclear fission began with the discovery of the neutron in 1932 by **James Chadwick** in England.
- Nuclear fission of heavy elements was discovered in 1938 by **German Otto Hahn** and **Fritz Strassmann.**
- It was explained theoretically in 1939 by Lise Meitner and Otto Robert Frisch.
- In nuclear physics, nuclear fission is a radioactive decay process in which the nucleus of an atom splits into smaller parts [lighter nuclei].
- The fission process often produces free neutrons and gamma photons [gamma rays], and releases a very large amount of energy [exothermic reaction].

[When urea is dissolved in water, the temperature of water solution falls. This reaction is called endothermic reaction].

Exothermic == Liberation of Heat during a reaction. [$CaCO_3$(calcium carbonate or lime) + H2O (water) → $Ca(OH)_2$(calcium hydroxide) + CO_2 + **HEAT**]

Endothermic == Absorption of Heat during a reaction. [Urea + Water]

- The nuclear fission process may take place spontaneously in some cases or may be induced by the excitation of the nucleus with a variety of particles (neutrons, protons, deuterons, or alpha particles) or with electromagnetic radiation in the form of gamma rays.
- In the fission process, radioactive products are formed, and several **neutrons** are emitted.
- These neutrons can **induce fission** in a nearby nucleus of fissionable material and release more neutrons causing a **chain reaction**.



Fissionable material → That can undergo nuclear fission chain reaction.

Fissile → That can undergo Controlled or Self-Sustained nuclear fission chain Reaction.

- If controlled in a nuclear reactor, such a chain reaction can be used to generate power. If uncontrolled [atomic bomb], it can lead to an enormous explosion.

- Uranium is the most common fissile used in nuclear reactors and nuclear weapons.
- Uranium isotopes in natural uranium are Uranium-238 or U-238 or **^{238}U (99.27%)** and Uranium 235 or U-235 or **^{235}U (0.72%)**.
- Uranium-235 can undergo fission when bombarded with slow neutrons only.
- Uranium-238 can undergo fission when bombarded with fast neutrons only.
- The nuclei of other heavy elements, such as **thorium** also fissionable, but with fast neutrons.

How Nuclear Fission Releases Energy?

- Nuclei consist of nucleons [neutrons + protons = mass number].
- The actual mass of a nucleus is always less than the sum of the masses of nucleons.
- This difference is known as the **mass defect** and is a measure of the total binding energy (and, hence, the stability) of the nucleus.
- This binding energy is released during the formation of a nucleus.
- This conversion of mass to energy follows Einstein's equation, $E = mc^2$, where E is the energy equivalent of a mass, m, and c is the velocity of light.

Common Fissile Material

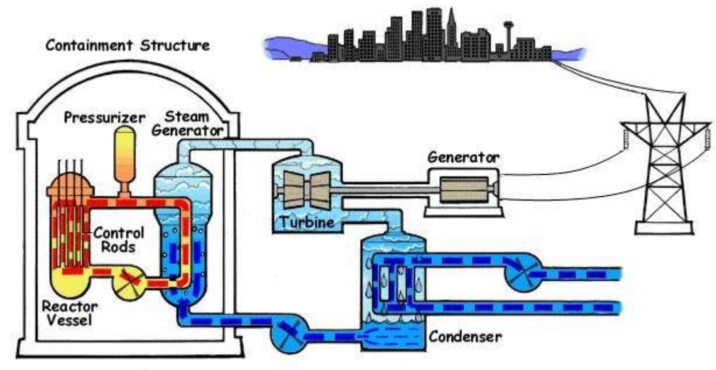
- **Uranium-235, Plutonium-239** and **Thorium-232** are the common fissile material.
- A slow neutron can be captured by a uranium-235 nucleus.
- A fast neutron will not be captured, so neutrons must be slowed down by moderation to increase their capture probability in fission reactors.
- Natural uranium is composed of 0.72% U-235 (the fissionable isotope), 99.27% U-238, and a trace quantity 0.0055% U-234.
- The 0.72% U-235 is not sufficient to produce a self-sustaining critical chain reaction.
- For light-water reactors, the fuel must be enriched to 2.5-3.5% U-235.
- While uranium-235 is the naturally occurring fissionable isotope, **Plutonium-239** can be produced by "breeding" it from uranium-238.
- Uranium-238, which makes up 99.3% of natural uranium, is **not fissionable by slow neutrons.**
- U-238 has a small probability for spontaneous fission and also a small probability of fission when bombarded with fast neutrons, but it is **not useful as a nuclear fuel source.**
- Thorium-232 is fissionable, so could conceivably be used as a nuclear fuel.
- The other isotope can undergo fission upon slow-neutron bombardment is uranium-233.

Uranium Enrichment

- Natural uranium is only 0.7% U-235, the fissionable isotope.
- The other 99.3% is U-238 which is not fissionable.
- The uranium is usually enriched to 2.5-3.5% U-235 for use in light water reactors.
- Centrifugal separators and laser enrichment procedures are used in uranium enrichment.
- The enriched uranium fuel used in fission reactors cannot be used to make a bomb.
- It takes enrichment to over 90% to obtain the fast chain reaction necessary for weapons applications.
- Enrichment to 15-30% is typical for breeder reactors.

Nuclear Reactor

- A nuclear reactor is a system that contains and controls sustained nuclear chain reactions.



Pic from: https://whatisnuclear.com/articles/nucreactor.html

- Fuel [Enriched uranium-235 or Plutonium-239] is placed into the reactor vessel along with a small neutron source.
- The neutrons start a chain reaction where each atom that splits releases more neutrons that cause other atoms to split.
- Each time an atom splits, it releases large amounts of energy in the form of heat.
- The heat is carried out of the reactor by coolant, which is most commonly just plain water.
- The coolant heats up and goes off to a turbine to spin a generator or drive shaft.
- The coolant is the material that passes through the core, transferring the heat from the fuel to a turbine. It could be water, heavy-water, liquid sodium, helium, or something else.
- The turbine transfers the heat from the coolant to electricity, just like in a fossil-fuel plant.
- The containment is the structure made of steel-reinforced concrete that separates the reactor from the environment. Chernobyl did not have a strong containment structure.

Nuclear Reactor Coolant

- A nuclear reactor coolant — usually water or molten salt — is circulated past the reactor core to absorb the heat that it generates.
- The heat is carried away from the reactor and is then used to generate steam.

Neutron Moderator

- A neutron moderator is a medium that **reduces the speed of fast neutrons**, thereby turning them into **thermal neutrons** capable of sustaining a nuclear chain reaction.
- When a large fissile atomic nucleus such as uranium-235 or plutonium-239 absorbs a neutron, it may undergo nuclear fission.
- The heavy nucleus splits into two or more lighter nuclei, (the fission products), releasing kinetic energy, gamma radiation, and free neutrons.
- A portion of these neutrons may later be absorbed by other fissile atoms and trigger further fission events, which release more neutrons, and so on. This is known as a **nuclear chain reaction.**
- To control such a nuclear chain reaction, neutron poisons and neutron moderators can change the portion of neutrons that will go on to cause more fission
- Commonly-used moderators include **regular (light) water** (in 74.8% of the world's reactors), **solid graphite** (20% of reactors), **heavy water** (5% of reactors) and **beryllium.**

Control Rods or Reactivity control

- The power output of the reactor is adjusted by controlling how many neutrons are able to create more fissions.
- Control rods that are made of a neutron poison are used to **absorb neutrons**.

Moderators slow down neutrons

Control Rods absorb neutrons

Moderators are like accelerators

Control Rods are like brakes

- Absorbing more neutrons in a control rod means that there are fewer neutrons available to cause fission.
- So pushing the control rod deeper into the reactor will reduce its power output, and extracting the control rod will increase it.

- Control rods are composed of chemical elements such as **boron, silver, indium and cadmium.**

Critical mass

- A critical mass is the smallest amount of fissile material needed for a sustained nuclear chain reaction.
- The critical mass of a fissionable material depends upon its nuclear properties, its density, its shape, its enrichment, its purity, its temperature, and its surroundings.
- When a nuclear chain reaction in a mass of fissile material is self-sustaining, the mass is said to be in a **critical state** in which there is no increase or decrease in power, temperature, or neutron population.

Criticality

- Criticality is a nuclear term that refers to the **balance of neutrons** in the system.
- Balance of neutrons can be achieved using moderators and control rods.
- **"Subcritical"** refers to a system where the loss rate of neutrons is greater than the production rate of neutrons and therefore the neutron population decreases as time goes on.
- **"Supercritical"** refers to a system where the production rate of neutrons is greater than the loss rate of neutrons and therefore the neutron population increases.
- When the neutron population remains constant, this means there is a perfect balance between production rate and loss rate, and the nuclear system is said to be **"critical."**
- When a reactor is starting up, the neutron population is increased slowly in a controlled manner, so that more neutrons are produced than are lost, and the nuclear reactor becomes supercritical.
- When the desired power level is achieved, the nuclear reactor is placed into a critical configuration to keep the neutron population and power constant.
- Finally, during shutdown, the reactor is placed in a subcritical configuration so that the neutron population and power decreases.
- Therefore, when a reactor is said to have **"gone critical,"** it actually means it is in a stable configuration producing a constant power.

Supercritical == Car [nuclear reactor] is accelerating.

Critical == Car is going at a constant speed.

Sub critical == Car is slowing down.

Neutron poison

- A neutron poison (also called a **neutron absorber** or a nuclear poison) is a substance with a **large neutron absorption cross-section**, in applications such as nuclear reactors.

Types of Nuclear Reactors

- There are various types of reactors based on moderators, coolants, technologies used.
- All commercial power reactors are based on nuclear fission.
- They generally use uranium and its product plutonium as nuclear fuel, though a thorium fuel cycle is also possible.
- Fission reactors can be divided roughly into two classes, depending on the energy of the neutrons that sustain the fission chain reaction: thermal reactors and fast neutron reactors.

Thermal Reactors and Fast Neutron Reactors [Breeder Reactors]

Thermal Reactors	Fast Neutron Reactors
Thermal reactors (the most common type of nuclear reactor) use **slowed or thermal neutrons** to keep up the fission of their fuel.	Fast neutron reactors use **fast neutrons** to cause fission in their fuel.

Almost all current reactors are of this type. Comparatively easy to build and operate.	Very rare due to complexity and costs. They are more difficult to build and more expensive to operate.
These contain neutron **moderator** materials that slow neutrons. The moderator is often also the coolant, usually water under high pressure.	They **do not have a neutron moderator**, and use less-moderating coolants.
High probability of fission due to slow neutrons. 2-5% Enriched fissile is sufficient to sustain a chain reaction.	Maintaining a chain reaction requires the fuel to be more **highly enriched in fissile material (about 20% or more)** due to the relatively lower probability of fission.
More radioactive waste	Fast reactors have the potential to produce **less radioactive waste** because all fissile is fissionable with fast neutrons.
Boiling water reactors (BWR), Pressurized water reactors (PWR) and heavy water reactors (HWR) operate with thermal neutrons [moderators used]	Breeder reactors operate with fast neutrons [moderators are not required]

Reactors based on Coolant and Moderator

- Light Water Reactors [LWR] and Hard Water reactors [HWR].

Light-water reactor (LWR)

- The light-water reactor (LWR) is a type of **thermal-neutron reactor** that uses **NORMAL WATER**, as opposed to heavy water, as both its **coolant and neutron moderator.**
- Thermal-neutron reactors are the most common type of nuclear reactor, and light-water reactors are the most common type of thermal-neutron reactor.
- There are three varieties of light-water reactors: the pressurized water reactor (PWR), the boiling water reactor (BWR), and (most designs of) the supercritical water reactor (SCWR).

Pressurized Water Reactor (PWR)

- The PWR uses regular water as a coolant.
- The primary cooling water is kept at very high pressure so it **does not boil**.
- Pressurized water reactors (PWRs) constitute the large majority of all Western nuclear power plants.
- In a PWR, the primary coolant (water) is pumped under high pressure to the reactor core where it is heated by the energy generated by the fission of atoms.
- The heated water then flows to a steam generator where it transfers its thermal energy to a secondary system where steam is generated and flows to turbines which, in turn, spin an electric generator.
- In contrast to a boiling water reactor, pressure in the primary coolant loop prevents the water from boiling within the reactor.
- PWRs were originally designed to serve as nuclear marine propulsion for nuclear submarines

Advantages of Pressurized water reactor (PWR)

- Very stable due to their tendency to produce less power as temperatures increase. Easier to operate from a stability standpoint.
- PWR turbine cycle loop is separate from the primary loop, so the water in the secondary loop is not contaminated by radioactive materials.
- The control rods are held by electromagnets and fall by gravity during power failure. Full insertion safely shuts down the primary nuclear reaction.
- PWRs are compact reactors that fit well in nuclear submarines and nuclear ships.

Disadvantages of Pressurized water reactor (PWR)

- The coolant water must be highly pressurized to remain liquid at high temperatures.
- This requires high strength piping and a heavy pressure vessel and hence increases construction costs.
- The higher pressure can increase the consequences of a loss-of-coolant accident.
- The high temperature water coolant with boric acid dissolved in it is corrosive to carbon steel (but not stainless steel) and can lead to radiation exposure.
- It is necessary to enrich [2-5%] the uranium fuel, which significantly increases the costs of fuel production.
- The requirement to enrich fuel for PWRs also presents a serious proliferation risk.
- PWRs are not scalable.

Boiling Water Reactor (BWR)

- It is the second most common type of electricity-generating nuclear reactor after the pressurized water reactor (PWR).
- The main difference between a BWR and PWR is that in a BWR, the reactor core heats water, which turns to steam and then drives a steam turbine. In a PWR, the reactor core heats water, which does not boil.
- This hot water then exchanges heat with a lower pressure water system, which turns to steam and drives the turbine.

Advantages of Boiling Water Reactor (BWR)

- The reactor vessel and associated components operate at a substantially lower pressure compared to PWR.
- Pressure vessel is subject to significantly less irradiation compared to a PWR.
- Operates at a lower nuclear fuel temperature.
- Fewer components due to no steam generators and no pressurizer vessel.
- Lower risk (probability) of a rupture causing loss of coolant compared to a PWR.
- Can operate at lower core power density levels using natural circulation without forced flow.
- BWRs do not use **boric acid** to control fission burn-up to avoid the production of tritium leading to less possibility of corrosion within the reactor vessel and piping.
- BWRs are ideally suited for peaceful uses like power generation, and desalinization, due to low cost, simplicity, and safety focus, which come at the expense of larger size and slightly lower thermal efficiency.

Disadvantages of Boiling Water Reactor (BWR)

- BWRs require more complex calculations for managing consumption of nuclear fuel. This also requires more instrumentation in the reactor core.
- There have been concerns raised about the pressure containment ability after **Fukushima I nuclear accidents**.
- Control rods are inserted from below for current BWR designs. In case of power failure, the reactor core can undergo significant damage and turn catastrophic.

Supercritical Water Reactor (SCWR)

- The supercritical water reactor (SCWR) uses supercritical water as the working fluid.

  Supercritical water oxidation or SCWO is a process that occurs in water at temperatures and pressures above a mixture's thermodynamic critical point.

  Under these conditions water becomes a fluid with unique properties that can be used to advantage in the destruction of hazardous wastes.

- SCWRs resemble light water reactors (LWRs) but operate at higher pressure and temperature like the pressurized water reactor (PWR) and with a direct once-through cycle like a boiling water reactor (BWR).

- The SCWR is a promising advanced nuclear system because of its high thermal efficiency and simpler design.
- It is still in development stage.

Advantages of Supercritical Water Reactor (SCWR)

- Supercritical water has excellent heat transfer properties allowing a high power density, a small core, and a small containment structure.
- As a BWR is simpler than a PWR, a SCWR is a lot simpler and more compact than a less-efficient BWR.
- There are no steam separators, steam dryers, internal recirculation pumps, or recirculation flow inside the pressure vessel.
- The stored thermal and radiologic energy in the smaller core would also be less than that of either a BWR's or a PWR's.
- Water is liquid at room temperature, cheap, non-toxic and transparent, simplifying inspection and repair.
- A fast SCWR could be a breeder reactor, like the proposed Clean And Environmentally Safe Advanced Reactor.
- A heavy-water SCWR could breed fuel from thorium (4x more abundant than uranium), with increased proliferation resistance over plutonium breeders.

Pressurized Heavy-Water Reactor (PHWR)

- Uses **heavy water (deuterium oxide D2O)** as its coolant and neutron moderator.
- The heavy water coolant is kept under pressure, allowing it to be heated to higher temperatures without boiling, much as in a pressurized water reactor.
- While heavy water is significantly **more expensive** than ordinary light water, it creates **greatly enhanced neutron economy**, allowing the reactor to **operate without fuel-enrichment facilities** (offsetting the additional expense of the heavy water) and enhancing the ability of the reactor to make use of alternate fuel cycles.

Advantages of Pressurized Heavy-Water Reactor (PHWR)

- It can be operated without expensive uranium enrichment facilities.
- The mechanical arrangement places most of the moderator at lower temperatures. The resulting thermal neutrons are "more thermal" making PHWR more efficient. So, PHWR uses fuel more efficiently.
- Since unenriched uranium fuel accumulates a lower density of fission products than enriched uranium fuel, it generates less heat, allowing more compact storage.

Disadvantages of Pressurized Heavy-Water Reactor (PHWR)

- The reduced energy content of natural uranium as compared to enriched uranium necessitates more frequent replacement of fuel.
- The increased rate of fuel movement through the reactor also results in higher volumes of spent fuel than in LWRs employing enriched uranium.

Nuclear proliferation and PHWR

- Opponents of heavy-water reactors suggest that such reactors pose a much greater risk of nuclear proliferation than comparable light water reactors.
- Natural Uranium-238 fissile [because enrichment is not required] of a heavy-water reactor is converted into plutonium-239, a fissile material suitable for use in nuclear weapons.
- As a result, if the fuel of a heavy-water reactor is changed frequently, significant amounts of weapons-grade plutonium can be chemically extracted from the irradiated natural uranium fuel by nuclear reprocessing **[Pakistan is pretty good at this]**.

- In this way, the materials necessary to construct a nuclear weapon can be obtained without any uranium enrichment.
- In addition, the use of heavy water as a moderator results in the production of small amounts of **tritium** when the deuterium nuclei in the heavy water absorb neutrons.
- Tritium is essential for the production of boosted fission weapons, which in turn enable the easier production of thermonuclear weapons, including neutron bombs.
- The proliferation risk of heavy-water reactors was demonstrated when India produced the plutonium for Operation Smiling Buddha, its first nuclear weapon test, by extraction from the spent fuel of a heavy-water research reactor known as the CIRUS reactor [Oh no!!].

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https://whatisnuclear.com/img/nrc-pwr-opt.gif

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Uranium - Uranium Distribution, Reserves and Production. Uranium in India. Nuclear Power Plants in India. Thorium - Advantages of Thorium, Thorium Distribution.

Atomic Minerals

- Uranium and Thorium are the main atomic minerals. Other atomic minerals are beryllium, lithium and zirconium.
- Uranium deposits occur in Singhbhum and Hazaribagh districts of Jharkhand, Gaya district of Bihar, and in the sedimentary rocks in Saharanpur district of Uttar Pradesh.
- But the largest source of uranium comprise the monazite sands.
- Monazite sands occur on east and west coasts and in some places in Bihar. But the largest concentration of **monazite** sand is on the **Kerala coast**.
- Over 15,200 tonnes of uranium is estimated to be contained in monazite.
- Some uranium is found in the copper mines of Udaipur in Rajasthan.
- India produces about 2 per cent of world's uranium. The total reserves of uranium are estimated at 30,480 tonnes.
- Thorium is also derived from monozite. The other mineral carrying thorium is thorianite.
- The known reserves of thorium in India are estimated to be between 457,000 and 508,000 tonnes. Kerala, Jharkhand, Bihar, Tamil Nadu and Rajasthan are the main producers.
- **Beryllium oxide** is used as a '**moderator**' in nuclear reactors. India has sufficient reserves of beryllium to meet her requirement of atomic power generation.
- Lithium is a light metal which is found in lepidolite and spodumene. Lepidolite is widely distributed in the mica belts of Jharkhand, Madhya Pradesh and Rajasthan.
- Zirconium is found along the Kerala coast and in alluvial rocks of Ranchi and Hazaribagh districts of Jharkhand.

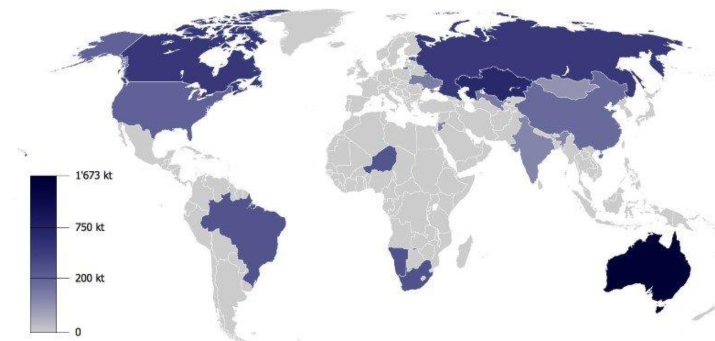
Uranium

- Uranium is a silvery-gray metallic radioactive chemical element. It is only naturally formed in supernova explosions.
- **Uranium, thorium**, and **potassium** are the main elements contributing to natural terrestrial radioactivity.
- Uranium has the chemical symbol U and atomic number 92.
- Uranium isotopes in natural uranium are **^{238}U (99.27%)** and **^{235}U (0.72%)**.
- All uranium isotopes are radioactive and fissionable. But only **^{235}U** is fissile (will support a **neutron-mediated chain reaction**).

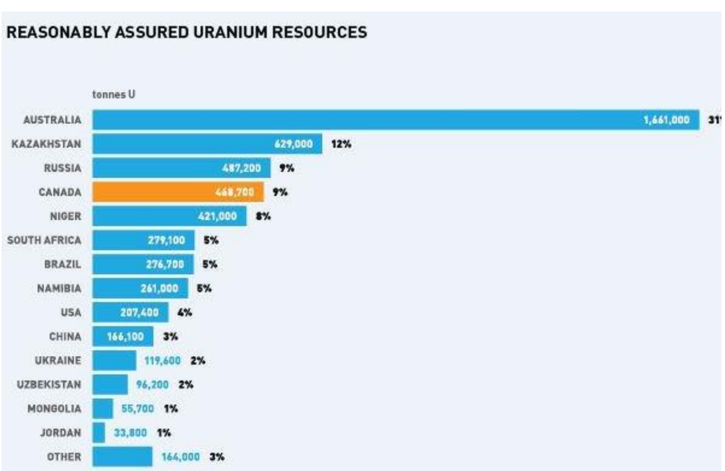
- Traces of Uranium are found everywhere. Commercial extraction is possible only in locations where the proportion of Uranium is adequate. There are very few such locations.

Distribution of Uranium Across the World

- Largest viable deposits are found in **Australia, Kazakhstan,** and **Canada**.
- Olympic Dam and the Ranger mine in Southern Australia are important mines in Australia.
- High-grade deposits are only found in the **Athabasca Basin** region of Canada.
- Cigar Lake, McArthur River basin in Canada are other important uranium mining sites.
- The Chu-Sarysu basin in central Kazakhstan alone accounts for over half of the country's known uranium resources.



List of Countries by Uranium Reserves and Production

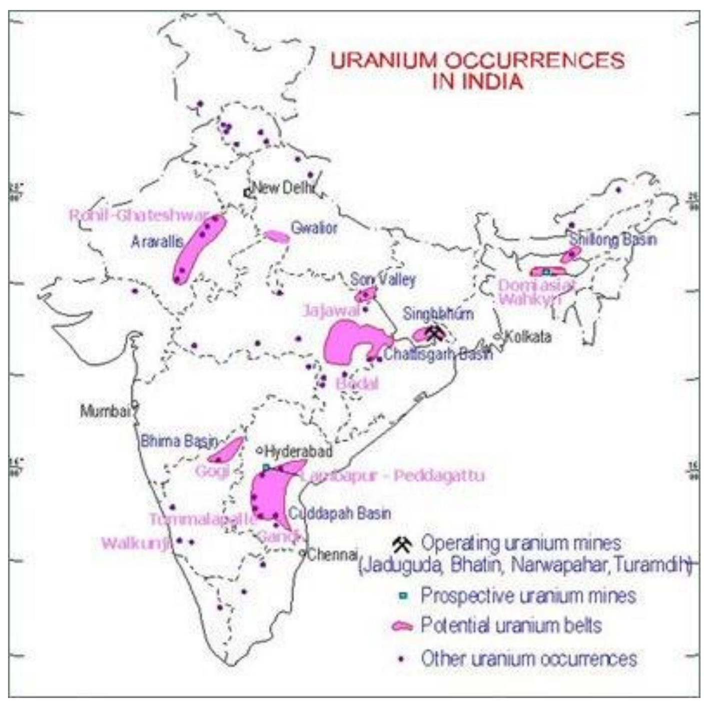


List of countries by uranium production

Rank	Country/Region	Uranium production (2013) (tonnes U)
	World	59,370
1	Kazakhstan	22,451
2	Canada	9,331
3	Australia	6,350

Uranium in India

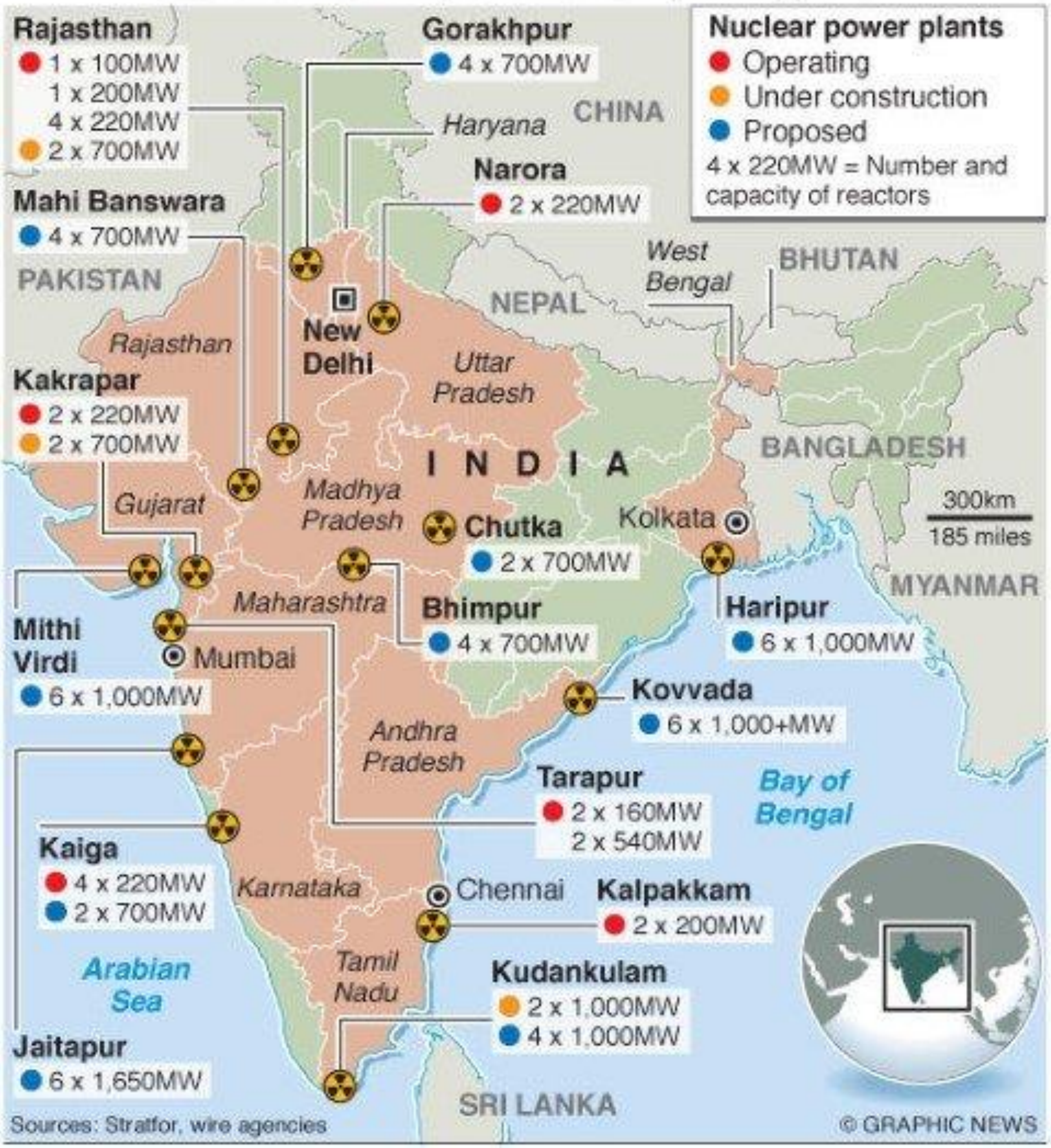
- India has no significant reserves of Uranium. All needs are met through imports.
- India imports thousands of tonnes of uranium from **Russia, Kazakhstan, France,** and **Uzbekistan.**
- India is trying hard to import uranium from Australia and Canada. There are some concerns regarding nuclear proliferation and other related issues which India is trying to sort out.
- Some quality reserves were recently discovered in parts of Andhra Pradesh and Telangana between **Seshachalam forest** and **Sresailam [Southern edge of Andhra to Southern edge of Telangana]**.

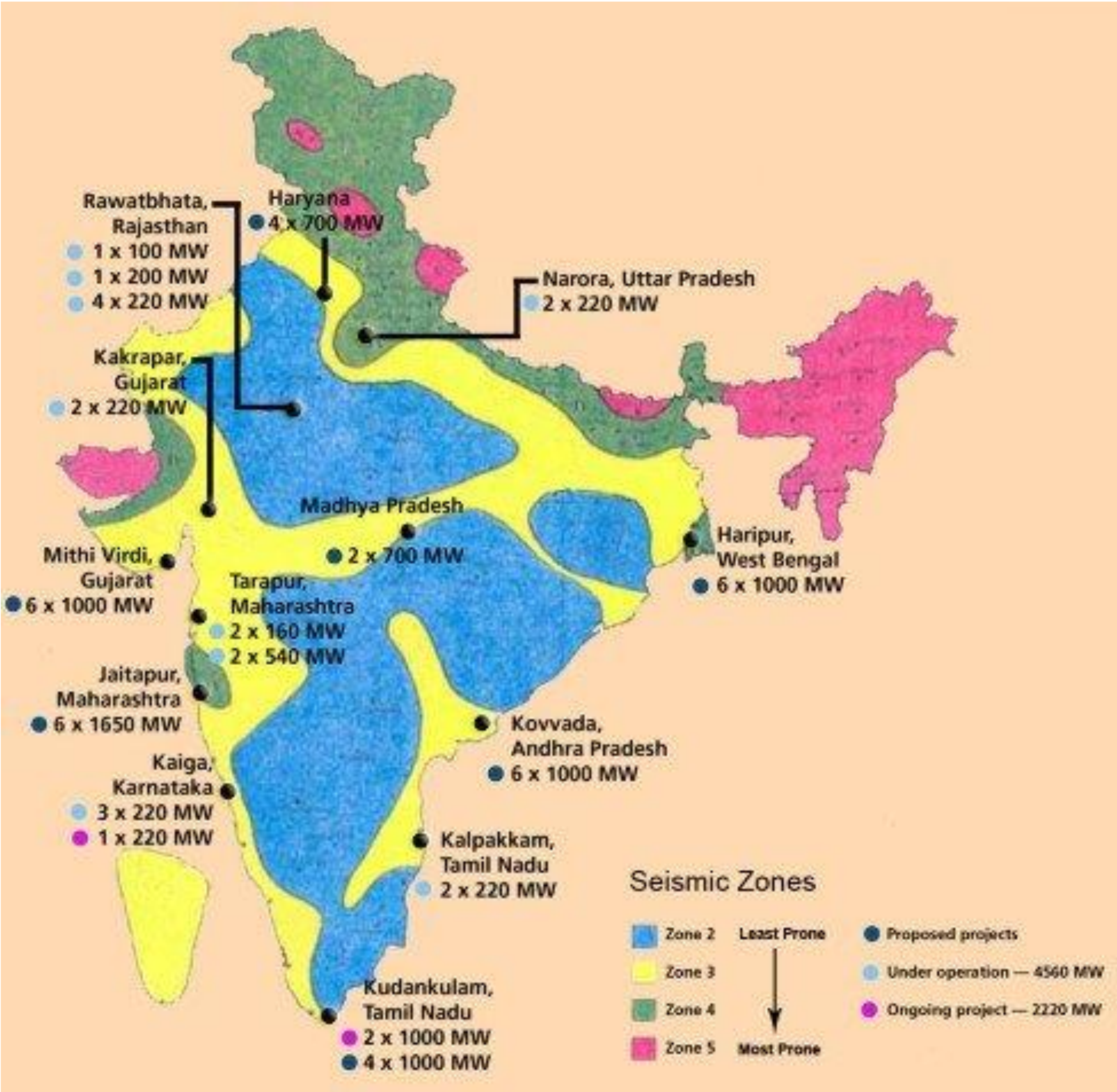


Nuclear Power Plants in India

India planning huge increase in nuclear power

India is making nuclear power one of its key policy initiatives, with plans to build 48 new reactors and boost output to 63,000 megawatts by 2032 – an almost 14-fold increase on current levels. The country's existing 20 nuclear reactors generate about 4,700 megawatts





Thorium

- Thorium is a chemical element with symbol Th and atomic number 90.
- It is one of only two significantly radioactive elements that still occur **naturally** in large quantities [other being **uranium**].
- Thorium metal is silvery and tarnishes black when exposed to air.
- Thorium is **weakly radioactive**: all its known isotopes are **unstable**, with the seven naturally occurring ones (thorium-227, 228, 229, 230, 231, 232, and 234).
- **Thorium-232** is the most stable isotope of thorium and accounts for nearly all natural thorium, with the other five natural isotopes occurring only in traces.
- Thorium is estimated to be about **three to four times more abundant than uranium** in the Earth's crust, and is chiefly refined from **monazite sands** [Monazite contains 2.5% thorium]**[Monazite is a widely scattered on the Kerala Coast].**

- Thorium is predicted to be able to replace uranium as nuclear fuel in nuclear reactors, but only a few thorium reactors have yet been completed.

Monazite – Rare Earth Metals

- Monazite is a reddish-brown phosphate mineral containing rare earth metals.
- Rare earths are a series of chemical elements found in the Earth's crust that are vital to many modern technologies, including consumer electronics, computers and networks, communications, clean energy, advanced transportation, health care, environmental mitigation, national defense, and many others.
- Because of their unique magnetic, luminescent, and electrochemical properties, these elements help make many technologies perform with reduced weight, reduced emissions, and energy consumption; or give them greater efficiency, performance, miniaturization, speed, durability, and thermal stability.
- There are 17 elements that are considered to be rare earth elements. [Scandium, Yttrium etc. — (names are very strange and hence I am avoiding them)]

Advantages of Thorium

- Proliferation is not easy: Weapons-grade fissionable material (U-233) is harder to retrieve safely from a thorium reactor [U-233 produced by transmuting thorium also contains U-232, a strong source of gamma radiation that makes it difficult to work with. Its daughter product, thallium-208, is equally difficult to handle and easy to detect].
- Thorium reactors produce far less waste than present-day reactors.
- Thorium produces 10 to 10,000 times less long-lived radioactive waste [minuscule waste that is generated is toxic for only three or four hundred years rather than thousands of years].
- They have the ability to burn up most of the highly radioactive and long-lasting minor actinides [fifteen radioactive metallic elements from actinium (atomic number 89) to lawrencium (atomic number 103) in the periodic table] that makes nuclear waste from Light Water Reactors a nuisance to deal with.
- Thorium reactors are cheaper because they have higher burn up.
- Thorium mining produces a single pure isotope, whereas the mixture of natural uranium isotopes must be **enriched** [enriching is costly] to function in most common reactor designs.
- Thorium cannot sustain a nuclear chain reaction without priming, so fission stops by default in an accelerator driven reactor.
- And five, thorium reactors are significantly more proliferation-resistant than present reactors. This is because the

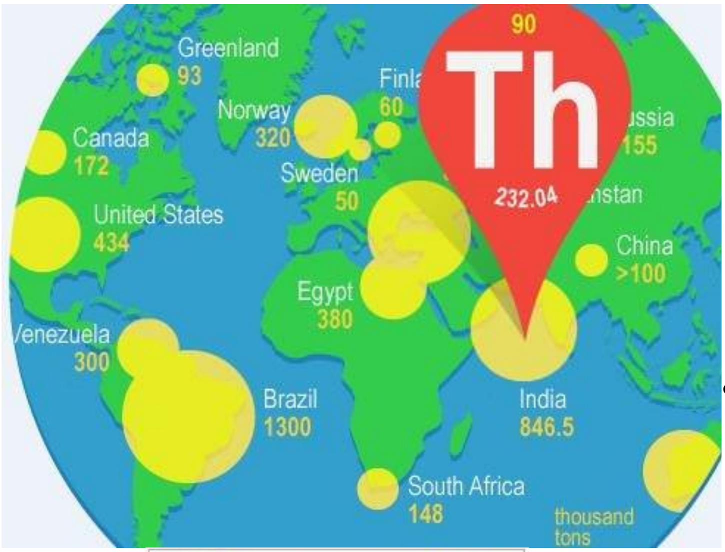
The mainstreaming of thorium reactors worldwide thus offers an enormous advantage to proliferation-resistance as well as the environment.

For India, it offers the added benefit that it can enter the export market [India has the largest reserves of thorium].

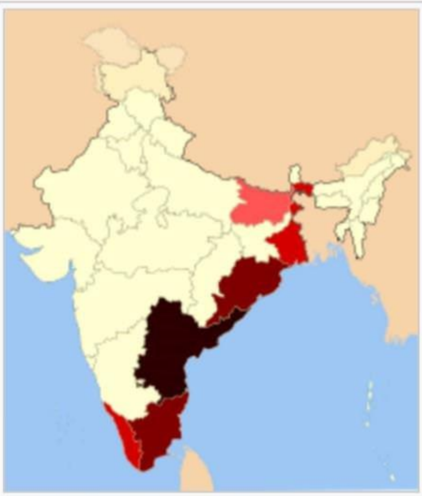
Scientists predict that the impact of climate change will be worse on India. Advancing the deployment of thorium reactors by four to six decades via a plutonium market might be the most effective step towards curtailing carbon emissions.

Thorium Distribution

- Thorium is several times more abundant in Earth's crust than all isotopes of uranium combined and thorium-232 is several hundred times more abundant than uranium-235.
- United States, Australia, and India have particularly large reserves of thorium.
- India and Australia are believed to possess more than half of world's thorium reserves.



USGS Estimates in tonnes (2011)	
Country	**Reserves**
India	963,000
United States	440,000
Australia	300,000
Canada	100,000
South Africa	35,000



India's thorium is mostly found in a contiguous belt formed by its eastern coastal states.
2012 reserve estimates:[9]
35% (Andhra Pradesh, excluding Telangana)
15–20% (Tamil Nadu, Odisha)
10–15% (Kerala, West Bengal)
0–5% (Bihar)

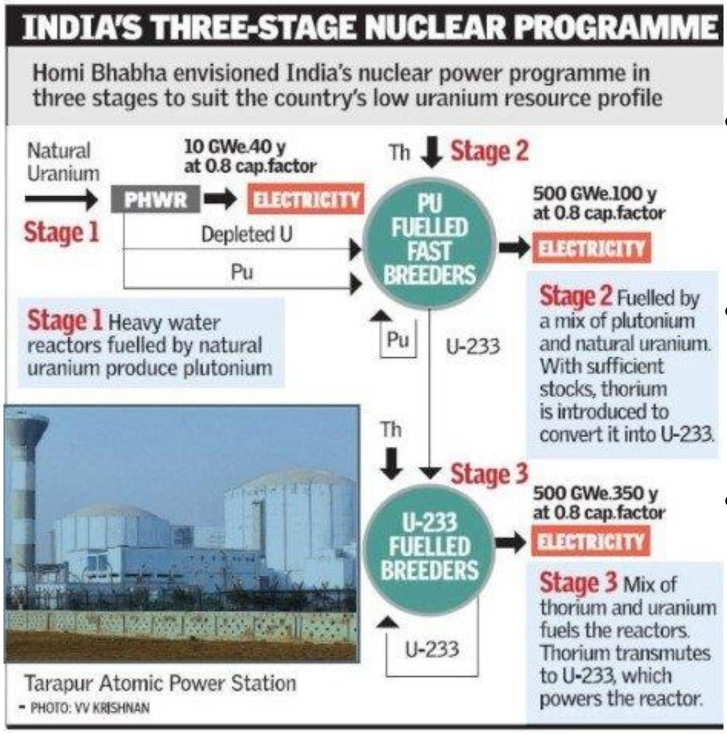
India's Three-Stage Nuclear Power Programme. Fast Breeder Reactor at Kalpakkam. What Hinders Deployment of Thorium-Fuelled Reactors In India? Solution to India's Fissile Shortage Problem.

India's Three-Stage Nuclear Power Programme

- India's three-stage nuclear power programme was formulated by **Homi Bhabha** in the 1950s to secure the country's long term energy independence, through the use of **uranium** and **thorium** reserves found in the **monazite sands** of coastal regions of South India.

The ultimate focus of the programme is on enabling the thorium reserves of India to be utilized in meeting the country's energy requirements.

- Thorium is particularly attractive for India, as it has only around 1–2% of the global uranium reserves, but one of the **largest shares of global thorium reserves**.
- However, at present thorium is not economically viable because global uranium prices are much lower.
- The recent **Indo-US Nuclear Deal** and the **NSG waiver**, which ended more than three decades of international isolation of the Indian civil nuclear programme, have created many hitherto unexplored alternatives for the success of the three-stage nuclear power programme.
- **Thorium itself is not a fissile material, and thus cannot undergo fission to produce energy.**
- Instead, it must be **transmuted to uranium-233** in a reactor fueled by other fissile materials [plutonium-239 or uranium-235].



- The first two stages, natural **uranium-fueled heavy water reactors** and **plutonium-fueled fast breeder reactors**, are intended to generate sufficient fissile material from India's limited uranium resources, so that all its vast thorium reserves can be fully utilized in the third stage of thermal breeder reactors.

Stage I – Pressurized Heavy Water Reactor [PHWR]

- In the first stage of the programme, natural **uranium** fuelled pressurized heavy water reactors (PHWR) produce electricity while generating **plutonium-239 as by-product**.

[U-238 → Plutonium-239 + Heat]

[In PWHR, enrichment of Uranium to improve concentration of U-235 is not required. U-238 can be directly fed into the reactor core]

[Natural uranium contains only 0.7% of the fissile isotope uranium-235. Most of the remaining 99.3% is uranium-238 which is not fissile but can be converted in a reactor to the fissile isotope plutonium-239].

[Heavy water (deuterium oxide, D 2O) is used as moderator and coolant in PHWR].

- PHWRs was a natural choice for implementing the first stage because it had the most **efficient reactor design [uranium enrichment not required]** in terms of uranium utilisation.
- India correctly calculated that it would be easier to create heavy water production facilities (required for PHWRs) than uranium enrichment facilities (required for LWRs).
- Almost the entire existing base of Indian nuclear power (4780 MW) is composed of first stage PHWRs, with the exception of the two Boiling Water Reactor (BWR) units at **Tarapur.**

Stage II – Fast Breeder Reactor

- In the second stage, fast breeder reactors (FBRs)[**moderators not required**] would use plutonium-239, recovered by reprocessing spent fuel from the first stage, and natural uranium.
- **In FBRs, plutonium-239 undergoes fission to produce energy, while the uranium-238 present in the fuel transmutes to additional plutonium-239.**

Why should Uranium-238 be transmuted to Plutonium-239?

Uranium-235 and Plutonium-239 can sustain a chain reaction. But Uranium-238 cannot sustain a chain reaction. So it is transmuted to Plutonium-239.

But Why U-238 and not U-235?

Natural uranium contains only 0.7% of the fissile isotope uranium-235. Most of the remaining 99.3% is uranium-238.

- Thus, the **Stage II FBRs are designed to "breed" more fuel than they consume**.
- Once the inventory of plutonium-239 is built up thorium can be introduced as a blanket material in the reactor and

transmuted to **uranium-233** for use in the third stage.

- The surplus plutonium bred in each fast reactor can be used to set up more such reactors, and might thus grow the Indian civil nuclear power capacity till the point where the third stage reactors using thorium as fuel can be brought online
- As of August 2014, India's first **Prototype Fast Breeder Reactor at Kalpakkam** had been delayed - with first criticality expected in 2015, 2016..and it drags on.

Stage III – Thorium Based Reactors

- A Stage III reactor or an Advanced nuclear power system involves a self-sustaining series of **thorium-232-uranium-233** fuelled reactors.
- This would be a thermal breeder reactor, which in principle can be refueled – after its initial fuel charge – using only naturally occurring thorium.
- According to replies given in Q&A in the Indian Parliament on two separate occasions, 19 August 2010 and 21 March 2012, large scale thorium deployment is only to be expected 3 – 4 decades after the commercial operation of fast breeder reactors. [2040-2070]
- As there is a long delay before direct thorium utilisation in the three-stage programme, the country is now looking at reactor designs that allow more direct use of thorium in parallel with the sequential three-stage programme
- Three options under consideration are the Accelerator Driven Systems (ADS), Advanced Heavy Water Reactor (AHWR) and Compact High Temperature Reactor

Prototype Fast Breeder Reactor at Kalpakkam

- The Prototype Fast Breeder Reactor (PFBR) is a 500 MWe fast breeder nuclear reactor presently being constructed at the Madras Atomic Power Station in Kalpakkam, India.
- The **Indira Gandhi Centre for Atomic Research (IGCAR)** is responsible for the design of this reactor.
- As of 2007 the reactor was expected to begin functioning in 2010 but now it is expected to achieve first criticality in March-April 2016.
- Construction is over and the owner/operator, **Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI)**, is awaiting clearance from the Atomic Energy Regulatory Board (AERB).
- Total costs, originally estimated at 3500 crore are now estimated at 5,677 crore.
- The Kalpakkam PFBR is using **uranium-238 not thorium**, to breed new fissile material, in a sodium-cooled fast reactor design.
- The surplus plutonium or uranium-233 for thorium reactors [U-238 transmutes into plutonium] from each fast reactor can be used to set up more such reactors and grow the nuclear capacity in tune with India's needs for power.
- The fact that PFBR will be cooled by liquid sodium creates additional safety requirements to isolate the coolant from the environment, since sodium explodes if it comes into contact with water and burns when in contact with air.

Below text is drawn from.. Fast forwarding to thorium-The Hindu, by JAIDEEP A. PRABHU

http://www.thehindu.com/opinion/op-ed/fast-forwarding-to-thorium/article7834156.ece

What Hinders Deployment of Thorium-Fuelled Reactors In India?

- Most people would assume that it is a limitation of technology. But instead, it is due to **shortage of uranium fuel** that is needed to **convert fertile fuel [thorium] into fissile** [fuel that can undergo sustained chain reaction].
- Scientists at the Bhabha Atomic Research Centre have successfully tested all

relevant thorium-related technologies in the laboratory.

- In fact, if pressed, India could probably begin full-scale deployment of thorium reactors in ten years.
- The single greatest hurdle, to answer the original question, is the critical shortage of fissile material.

What is a fissile material?

- A fissile material is one that can sustain a chain reaction upon bombardment by neutrons.
- Thorium is by itself **fertile**, meaning that it can **transmute into a fissile radioisotope [U-233]** but cannot itself keep a chain reaction going.
- In a thorium reactor, a fissile material like uranium or plutonium is blanketed by thorium.
- The fissile material, also called a driver in this case, drives the chain reaction to produce energy while simultaneously transmuting the fertile material into fissile material.
- India has very modest deposits of uranium and some of the world's largest sources of thorium. It was keeping this in mind that in 1954, Homi Bhabha envisioned India's nuclear power programme in three stages to suit the country's resource profile.

1. In the first stage, heavy water reactors fuelled by natural uranium would produce **plutonium [U-238 will be transmuted to Plutonium 239 in PHWR]**;
2. the second stage would initially be fuelled by a mix of the plutonium from the first stage and natural uranium. This uranium would transmute into more plutonium and once sufficient stocks have been built up, thorium would be introduced into the fuel cycle to convert it into **uranium 233 for the third stage [thorium will be transmuted to U-233 with the help plutonium 239]**.
3. In the final stage, a **mix of thorium and uranium** fuels the reactors. The thorium transmutes to U-233 which powers the reactor. Fresh thorium can replace the depleted thorium [can be totally done away with uranium which is very scares in India] in the reactor core, making it **essentially a thorium-fuelled reactor** [**thorium keeps transmuting into U-233**. It is U-233 that generates the energy].

Present State of India's Three-Stage Nuclear Power Programme

- After decades of operating pressurized heavy-water reactors (PHWR), India is finally ready to start the second stage.
- A 500 MW Prototype Fast Breeder Reactor (PFBR) at Kalpakkam is set to achieve criticality any day now and four more fast breeder reactors have been sanctioned, two at the same site and two elsewhere.
- However, experts estimate that it would take India many more FBRs and at least another four decades before it has built up a sufficient fissile material inventory to launch the third stage.

Solution to India's Fissile Shortage Problem – Procuring Fissile Material Plutonium

- The obvious solution to India's shortage of fissile material is to procure it from the international market.

Favourable Conditions for Plutonium Trade

- **As yet, there exists no commerce in plutonium though there is no law that expressly forbids it.**
- In fact, most nuclear treaties such as the Convention on the Physical Protection of Nuclear Material address **only U-235 and U-233**.
- This is because Plutonium has so far not been considered a material suited for peaceful purposes.
- The Non-Proliferation Treaty (NPT) merely mandates that special fissionable material — which includes plutonium — if transferred, be done so under safeguards.
- Thus, the legal rubric for safeguarded sale of plutonium and safety procedures for moving radioactive spent fuel and

plutonium already exists but it is not too complicated as in case Uranium.

- Japan and the U.K. who are looking to reduce their stockpile of plutonium will certainly be happy to sell it to India.

What compelling reason does the world have to accommodate India?

- India's FBRs that are tasked for civilian purposes and can be brought under international safeguards in a system similar to the Indo-U.S. nuclear deal.
- FBRs and large quantities of fissile material can easily be redirected towards weapons programme. But India has shown no inclination to do so until now.

Obstacles

- The U.S. could perhaps emerge as the greatest obstacle to plutonium commerce.
- U.S. cannot prevent countries from trading in plutonium, it has the power to make it uncomfortable for them via sanctions, reduced scientific cooperation, and other mechanisms.
- The strong non-proliferation lobby in the U.S. would not like a non-signatory of the NPT [India] to open and regulate trade in plutonium.
- The challenge for Delhi is to convince Washington to sponsor rather than oppose such a venture.

https://en.wikipedia.org/wiki/Occurrence_of_thorium

http://www.thehindu.com/opinion/op-ed/fast-forwarding-to-thorium/article7834156.ece

https://en.wikipedia.org/wiki/India%27s_three-stage_nuclear_power_programme