MODULE 01: LAND AND SEA: FORMATION AND DISTRIBUTION

The time period from the formation of the Earth (4.5 Ga) to the establishment of plate tectonics at the beginning of the Proterozoic (2.5 Ga) remains largely hidden and unknown. During this time period, the ocean, atmosphere, and continents formed, and the geomorphic processes and physical processes that allowed the development and evolution of life were established. Our knowledge of these beginnings is scant, with theories changing as each new line of evidence emerges. Perhaps most troubling is that we have no coherent, unified theory that simplifies our understanding of the Earth's beginnings.

The key idea necessary for the development of a unified theory that explains the origin of the ocean and continents is the recognition that the timing of the growth of continental crust is an earmark for the presence of abundant water on the surface of the Earth and its entry into the mantle by subduction. Strontium isotopes, europium anomalies, and zircon populations all suggest that rapid growth of the continental crust did not begin until 3.0 Ga when the Earth was already 1.5 billion years old. The implication is that widespread hydration of the oceanic crust did not occur until about 3.0 Ga; thus volumes of water sufficient to cover the Archean analogues to mid-ocean spreading ridges did not exist prior to this time. No existing theory of ocean origin by outgassing or early and rapid accretion on a young Earth survives falsification. The unifying theory that explains both the origin of the ocean and the continents is the slow and gradual accumulation of water on the surface of the Earth by extraterrestrial accretion.

The surface of earth is made up of land and water. About 71 percent of its surface consists of vast basins which are full of water and are known as the oceans, while 29 percent of its area is dry land, known as the continents. Land and sea being fundamental relief features of the globe are considered as relief features of the first order. Salisbury (1919), on the basis of relief, has divided the earth’s relief into three categories- (1) First order landforms (examples Continents and Oceans), (2) Second order landforms (examples mountains, plateaus, plains, oceanic ridges, guyots etc.), and (3) Third order landforms (examples hills, valleys, deltas, rivers and lakes etc.,). Thus, continents and oceans are the most significant and fundamental features of the earth. It is, therefore, desirable to inquire into their mode of possible origin and evolution. There emerged different views, concepts, hypotheses and theories put forth by scientists from time to time regarding the origin and distribution of continents and ocean basins. The formation of land and sea became the most important event, after the formation of the earth. According to Dana (1846), the continents and ocean basins on the earth have not changed from their original form. Ancient continents and primary oceans still exist, although their latitudinal or global position has undergone changes due to known to unknown forces, related with continental drift, convection currents and plate tectonics.

Before examining the views regarding origin and distribution of continents and oceans it is important to know the characteristics features of the distributional patterns and arrangement of the continents and ocean basins (i.e. land and Sea) as seen at present. According to Krummel, about 70.8 percent of the total surface area of the globe is under water, while remaining 29.2 percent is represented by the continental landmasses.

CHARACTERISTICS OF LAND AND WATER DISTRIBUTION:

If we look at the globe and examine the general features of land and water distribution, a certain pattern would automatically become clear. The distribution of different continents and oceans in both the hemisphere is not uniform. The following characteristic features of their distributional patterns and arrangements may be highlighted:

i. Nearly 29 percent of the earth constitutes the lithosphere, while 71 percent comprises hydrosphere.

ii. A circle drawn from New Zealand as the centre comprises Water Hemisphere, which has 95 percent water, while the circle drawn form Briltany (France), having 81 percent land comprises Land Hemisphere.

iii. There is overwhelming dominance of land mass in the northern hemisphere. More than 75 percent of the total land area of the globe is situated to north of the equator.

iv. Northern hemisphere bounds in land about 60 percent, whereas the Southern Hemisphere has an abundance of water comprising of 81 percent.

v. Continents are arranged in roughly triangular shape. Most of the continents have their bases in the north tapering in the south while their apices are pointed towards south. Australia and antarctica are the exceptions to this rule.

vi. The oceans have also some what triangular shape. Contrary to the continents the bases of oceans are in the south and tapering in the north.

vii. The north pole is surrounded by oceanic water (i.e. Arctic Ocean) while south pole is surrounded by land area i.e. Antarctic continent.

viii. Continents and oceans are situated anti-podal to each other, which is significant for maintain isostatic equilibrium. Patagonia and New Zealand are only two cases of exceptions to this general rule.

ix. Island arcs and folded mountains are situated on the borders of continents.

x. Continents have largely granite rocks, while the ocean basins have dense basaltic rocks.

xi. Continents have elevated landforms (i.e. Mt. Everest – 8850 mts) while oceans have deepest points (i.e. Mariana Trench- 11,065 mts). The Alps-Himalayan range is the largest (10,000 km long) range on the continents, while the oceans have a system of submarine ridges (more than 40,000 km long).

xii. Oceans, like their counterparts, have features like ridges, plateaus, slopes, canyons, plains, deeps, and trenches etc. Besides, oceans abound in minerals and energy resources, seafood etc. and serve as means of transport more than the continents do.

Permanency of Continents and Ocean Basins

Several scholars and scientist have presented various views on the origin and permanency of continents and oceans. These views may be grouped into two classes as the following:

(1) Orthodox views

(2) Continental drift

(1) **Orthodox views**: Scholars who believe in the permanency of continents and oceans, base their ideas on contraction and other causes. The scholars belong to this class are Chamberlin, Moulton, Jeffreys, Jeans, Sollas, Lapworh, and Kelvin etc.

(2) **Continental drift**: Those scholars who believe in continental drift caused by various factors are Taylor, Wegener, Holmes, Jolly, and Daly etc. These theories have been testified by plate tectonics.

Evidences of Permanency of Continents:

The propagonists of permanency of continents and ocean believe that here has been no large scale movement of continents and oceans, instead they have remained stable. Dana has given the following evidences in support of his view:

i. Sediments in the coastal areas are different from deep marine deposits, which do not occur on continents anywhere.

ii. It has been established trough sounding techniques that the emergence of islands from ocean bottoms is impossible.

iii. Sedimentary rocks of islands are different from those of continents.

iv. Continents made of lighter sial can neither float on denser sima, nor subside in it.

v. Parts of continents may submerge for some-lime, but the entire continent cannot.

vi. The presence of fossils in distant lands can be explained through the existence of land bridges in ancient times.

Evidences of Continental Drift:

Scholars have put forward the following pleas in favour of continental drift:

1. The geological and geographical similarities on both the coasts of the Atlantic can only be explained through continental drift. Du Toit on the basis of geological evidences opines that both coasts of the Atlantic were joined together in the past.

2. Evidence of Carboniferous glaciation are present in distant lands of South America, Australia, India, South Africa etc. Glossopteris flora also exists here. It proves that the South Pole existed near Natal (in South Africa) in ancient times and later the various lands drifted apart.
3. The idea of land bridges cannot be proved, because continents formed of lighter material (SIAL) cannot submerge in denser SIMA. Moreover, when an iceberg breaks, it does not subside, but gets displaced horizontally only.
4. Magnetism of rocks and the shifting positions of the magnetic pole have supported the idea of continental drift.
5. According to Blackett, India and Britain have definitely drifted away. Hess and Dietz also supported this view.

In the light of the above points, continental drift has emerged a reality.

Origin of Land and Sea:

The land and sea are the main features of the surface of the earth. The question is, how did they originate? In deciding this question or solving this problem the chief things that are to be taken into consideration are two: Firstly, that the earth has cooled down from a gaseous state and its interior is still very hot. Secondly, that there is a definite plan or order underlying the distribution of land and water on the surface of the earth. Taking into view these factors various theories have been put forwarded from time to time as the following:

I. Early Theories

II. Theories based on Contraction and

III. Theories based on Continental Drift

I. **Early theories**: after the origin, the planet earth was in hot, gaseous and liquid state. According to Kelvin when earth was in gaseous state, the primordial matter got concentrated in certain places which formed continents, on its condensation. The oceanic depressions formed at those places where material was less. According to Solas the continents and oceans were formed on liquid earth due to variations in atmospheric pressure. Chamberlin and Moulton suggest irregular accumulation of planetesimals as the cause of formation of continents and oceans. However, all these views are based on imagination only.

II. **Theories based on Contraction**: Those scholars who believe in contraction presented that the earth has gradually cooled and solidified from a hot gaseous and liquid state. The crust got cooled and solidified first. Gradually, the inner part also started to cool down. The crust had to adjust itself with the contracting layer. In this condition the elevated parts became continents, while the depressed parts formed as the ocean basins. There are numerous theories on the basis of contraction, but few of them only specially mentioned as the following:

1. Lothian Green's Tetrahedral theory
2. Lapworth and Love's theory based on warping
3. Theory of Jeans and Sollas based on the origin of the Moon.
4. Daly's theory of sliding continents
5. Gregory's theory of land bridges

1. **Lothian Green's Tetrahedral Theory**:

The tetrahedral theory is an obsolete scientific theory attempting to explain the arrangement of the continents and ocean on the Earth by referring to the geometry of a tetrahedron. Although it was a historically interesting theory in the late 19th and early 20th century, it was superseded by the concepts of continental drift and modern plate tectonics. This theory was proposed by William Lothian Green in 1875.This theory is based on geometrical principles. In fact, it a modification of Elie de Beaumont's pentagonal dodecahedral theory with 12 faces. His concept was supported by Fairbrain. Later RS Morgan & SW Woolridge worked on Lothian's Principles. Lothian's theory is based on the characteristics of a tetrahedron which is a solid body having four equal plane surfaces, each of which is an equilateral triangle. Lothian postulated his theory after considering the characteristics of the distributional pattern of land and water on the globe.

Lothian Green

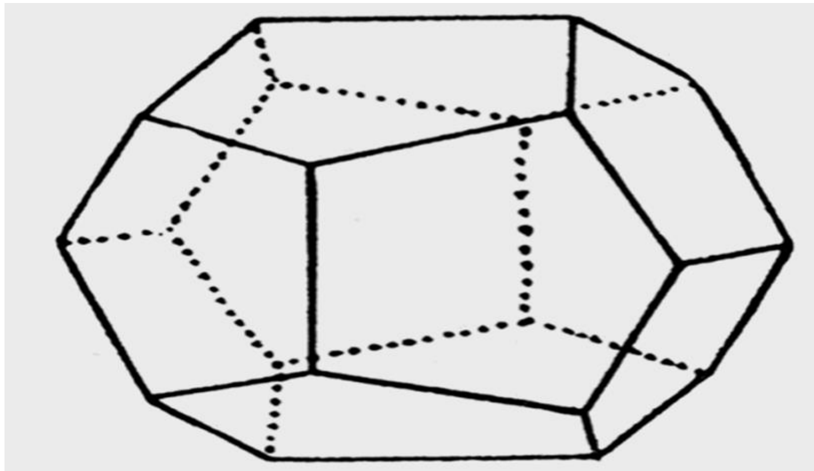


Fig1.1: Image of hypothesis with 12 faces

Platonic solid is a regular, convex polyhedron constructed by congruent (identical in shape and size) regular (all angles equal and all sides equal) polygonal faces having same number of faces meeting at each vertex.

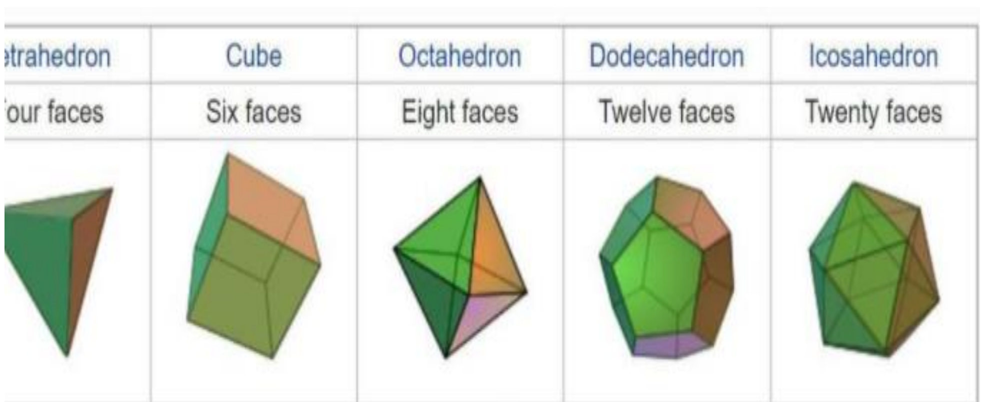


Fig1.2: Image of different geometrical shapes which were used to postulate the hypotheses of origin of continents and ocean basins. The first one is a tetrahedron.

Barring a few merits and demerits the theory attempted to explain apparent anomalies in the distribution of land and water on the Earth's surface:

(1) Dominance of land areas in the northern hemisphere and water areas in the southern hemisphere;

(2) Both continents and oceans have roughly triangular shape;

(3) The situation of continuous ring of land around north polar area and location of south pole in land area surrounded by water from all sides;

(4) Exactly opposite the earth from land is almost always water;

(5) The largest extent of Pacific Ocean occupies about one third of earth’s surface; and

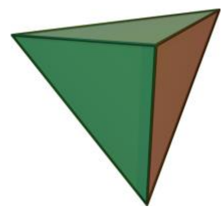
(6) A chain of fold mountains situated around the Pacific Ocean.

Lothian based his theory on the following two basic geometric principles:

(i) A spere is that body which contains the largest volute with respect to its surface area;

(ii) A tetrahedron is that body which contains the least volume with respect to its surface area.

According to theory, process of cooling, to take the form of a tetrahedron or triangular pyramid, with four faces and four corners or coigns. It has minimum volume for its area.



A tetrahedron is placed over a sphere of water in such a way that it does not cover the sphere completely. In this case, its corners and edges will appear out of water and represent the continents. Its four faces will represent the ocean. After placing one of its vertex over the south pole its remaining three vertices are adjusted around the north pole. Its three vertices will be in the northern hemisphere and will represent three continents: Americas, Europe and Asia, whose bases are in the north and vertices in the south. The fourth continent will be on its fourth corner (south pole) and will represent Antarctica. Depressions and faces of the pyramid represent oceans. The three oceans will be on its three faces and the fourth one on north pole. Lothian green stated that tetrahedron shape of the earth cannot be exactly tetrahedron. Its coigns (corners) will not be sharp but round reach out the edges to form continents. In late 19th & 20th century superseded by continental drift and plate tectonics.

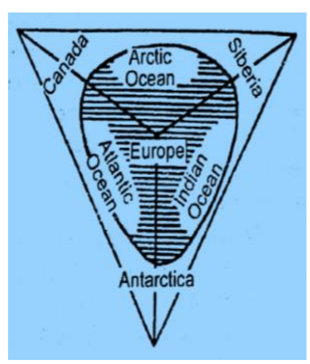


Fig1.3: Distribution of land and water on a tetrahedron

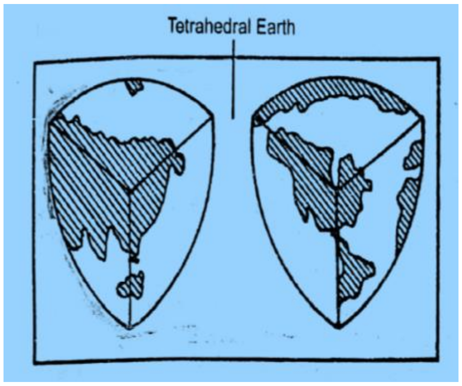


Fig1.4: A tetrahedron place on a sphere

Criticism:

Merits:

- Tetrahedral theory is the antipodal position of continents and ocean basins
- This represents the actual distribution of continents and oceans.

Demerits:

- Corners would sink to form a stable shape. Small globe can but enormous earth cannot.
- Again, continents are made of light SIAL and oceans made of SIMA (heavier). Contraction could not account for distribution of continents without considering SIMA and SIAL.
- Balance of the earth in the form of a tetrahedron while rotating on an apex cannot be maintained.
- Earth rotates rapidly on its axis & spherical earth cannot be converted into a tetrahedron while contracting on cooling.
- Hypothesis of permanency of continents and ocean basins has been rejected by plate tectonic that validated continental drift concept.

MODULE 00: ISOSTASY

Introduction:

There are a wide variety of relief features with changing magnitudes, such as huge mountains, dissected plateaus, flat plains, lakes, low lying seas and oceanic basins, faults and rift valleys etc., lies on the surface of the earth. All these land features differ from each other in terms of their height, width, size and area etc., and they are probably balanced by certain definite principles, otherwise these would have not been maintained a state of isostatic balance and would not be in their present form. There must exist certain invisible energies behind producing such balance which called as “Isostasy”. As soon as this balance is distressed, there must flinch ferocious earth crustal movements and plate tectonic procedures.

Objectives of the present module are as the following:

- To define the isostasy
- To understand the development of the isostasy concept
- To understand the concepts of airy, Pratt and Jolly

In the present module of isostasy, you are going to learn the following sections:

4.1. meaning and definitions of isostasy

4.2. Discovery of the concept of isostasy

4.3. the concept of Pratt

4.4 the Concept of Airy

4.5 Isostatic adjustments on the earth surface

4.1 Meaning and Definitions of Isostasy

The word ‘isostacy’ is derived from the Greek word “iso-stasios” which means equipoise or equal standing. In other words, the gravitational adjustment of earth’s crust is isostasy, a state of balance. The term isostasy was first used by American geologist Clarence E. Dutton in 1889 to explain his view to indicate “the state of mechanical equilibrium under the control of natural laws between the high upstanding areas of the earth’s surface, mountain ranges, plateaus, and contiguous lowlands etc., exists over the rotating earth planet’. According to Dutton the upstanding parts of earth (mountains, plateaus, plains and ocean basins) must be compensated by lighter rock material from beneath so that the crustal reliefs should remain in mechanical stability.

It means the less dense materials of the earth's surface (SIAL) must float over the denser magma (SIMA) of the earth's interior.

Encyclopaedia Britannica defines isostasy as "a principle in earth science whereby one understands why continents stand nearly three miles above the floor of deep oceans and a why a major chain so high above the general continental surface".

S.W. Wooldridge and R.S. Morgan (1959) stated that, "Isostasy is a complex body of ideas dealing with the relation between the outer crust of a rotating earth and the underlying layers".

According to **J.A. Steers (1961)**, "this doctrine states that wherever equilibrium exists on the earth's surface, equal mass must underlie equal surface area".

According to **Arthur Holmes (1975)**, "Isostasy is for the ideal condition of a gravitational equilibrium that controls the height of continents and ocean floors in accordance with the densities of their underlying rocks".

4.2. Discovery of the concept of isostasy

The concept of isostasy has been comprehended in a different way by various geologists all of sudden but its concept raised out of steady thinking in terms of gravitational attraction of giant mountainous masses. A brief history of the discovery of isostasy concept is as the following:

Even though the term isostasy was first used by **C.E. Dutton**, the knowledge was first put forth by **Pratt** (1855, 1861), who analysed the theory in detail. Prior to Pratt, **Pierre Bouguer**, the French Scientist, during his geodetic survey in the Andes mountains in 1735-45 identified that the deflection of the plumb line towards the towering volcanic peak of Chimborazo was very less than he had estimated and recorded his suspicion that the gravitational attraction of the Andes is much smaller than that to be expected from the mass represented by these mountains.

Likewise, **Boscovich**, a French scientist, preached that high temperature in the earth core triggered expansion in rocks beneath mountains, thus diminishing their density. The height of the mountains compensated for their density.

Sir George B. Airy (1851), the Astronomer Royal stated that the continents which are made up with less dense material SIAL, are floating over the substratum which is made up of denser material SIMA.

Similar discrepancies were noticed during the trigonometrical and geodetic survey of the Indo-Gangetic plain for the determination of latitudes under the supervision of **Sir George Everest**, the then surveyor general of India in 1859. When the difference in latitude between Kalyanpur and Kalyana (603 km due north, about longitude 78°E) was determined by both direct triangulation method and astronomical methods, it was fond that the two results differed by 5.236 seconds of arc. The latitudinal distance measured with the help of the astronomical method was less by 5.236 seconds of arc which is equal to a distance of 108 meters on the ground. The discrepancy was considered to be due to the attraction exerted by the enormous mass of the Himalayas and the deflection of the plumb-bob used for levelling the astronomical instrument of Kalyana which was close to the Himalayas.

Archdeacon Pratt astonished a lot to identify the above variations due to the distance between Kalyana and the Himalayas was barely 96 km. Pratt, therefore, concluded that the afore mentioned variation was because of the attraction of the Himalayas on the plumb line. The point to be observed here is that astronomical determination of latitudes is done by the direction of the independently suspensed plumb at a place. The plumb line shows the attraction direction at a place. As the shape of the earth is Geoid, the plumb line on the sea level get deflected a bit instead of being vertical.

4.3 THE CONCEPT OF ARCHDEACON PRATT:

While studying the above gravitational variances, Pratt opined that the Himalayas had resulted the deflection in plumb line. So as to unravel the problem, Pratt has calculated the gravitational attraction of the Himalayas taking their average density equal to that of the earth crustal rocks as 2.7 grm/cm^3. He was amazed to find out the actual difference between the two places (i.e. in geodetic survey of Kalyana and Kalyanpur) should have been 15.885" instead of 5.236". This means the Himalayas'' attraction should have been greater than that was observed.

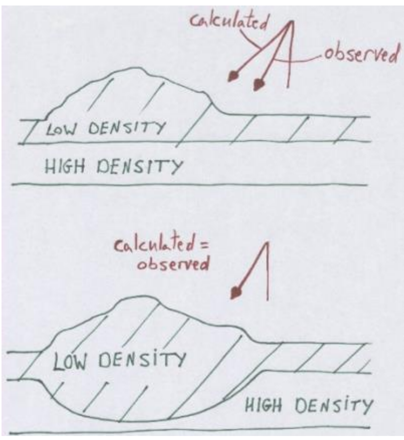


Fig. 1: The deflection of plumb bob near mountain chains is less than expected

In order to unravel the problem of fewer attraction of the Himalayas, Pratt has presented a couple of alternatives:

i. The Himalayan mountains formed with rocks of low density
ii. Local heavy attraction because of major landforms was compensated for by some deficiency of density below the surface.

In the above circumstances, Himalayan mountains attraction might have been low so that the plumb line deflected less. The second alternative supported by the several scholars. In views of Pratt, there is inversely proportional relationship between density and height of the reliefs; therefore, the land features above the level of compensation above which there is a difference in the density of different columns of land, but below it there exists equal density. There would be no change in density within one column but it changes from one column to another above the level of compensation. Accordingly, the central theme of the Pratt's isostasy theory can be expressed as "Column of uniform depth with varying density".

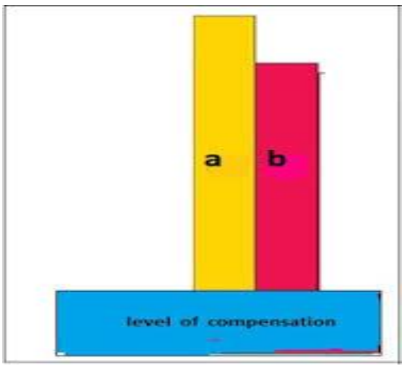


Fig 2: Line of Compensation

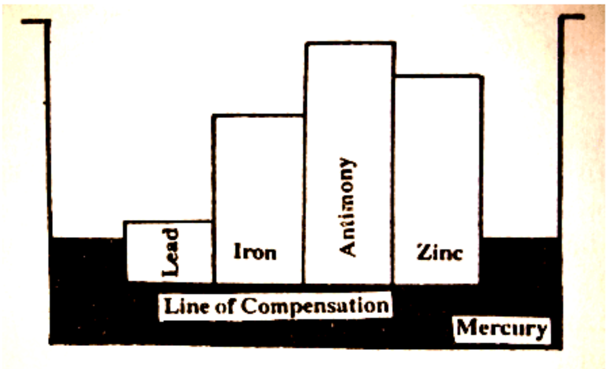


Fig. 3: Level of Compensation and blocks of different metals

According to Pratt equal surface area must underlie equal mass along the line of compensation. This statement may be explained with an example (Fig.2). There are two columns, A and B, along the line of compensation. Both the columns, A and B, have equal surface area but there is difference in their height. Both the columns must have equal mass along the line of compensation, so the density of column A should be less than the density of column B so that the weight of both the columns become equal along the line of compensation. Thus, Pratt's concept of inverse relationship between the height of different columns and their respective densities may be expressed in the following manner- 'bigger the column lesser the density and smaller the column, greater the density.' According to Pratt density varies only in the lithosphere and not in the pyrosphere and barysphere. Thus, Pratt's concept of isostasy was related to the 'law of compensation' and NOT to 'the law of floatation.' According to Pratt different relief features are standing only because of the fact that their respective mass is equal along the line of compensation because of their varying densities. This concept may be explained with the help of an example (fig.3).

4.4. THE CONCEPT OF SIR GEORGE AIRY

Sir George Airy (1855), an Astronomer Royal, suggested that the earth's crust is supported by underlying denser material and that the weight of mountains is balanced by light materials extending as roots in the denser medium. According to **Archimedes**, a floating body displaces liquid equal to the volume of the submerged part of the floating body. The greater the part of the body above the liquid in which it is floating, the greater the part of the body inside the liquid. According to airy, continents are supposed to be floating on the denser material SIMA constituting the substratum. In other words, '**SiAl**' is floating over '**SiMa**'. As stated earlier, the whole controversy revolved around certain features regarding the smaller gravitative attraction of the Himalayan mountains.

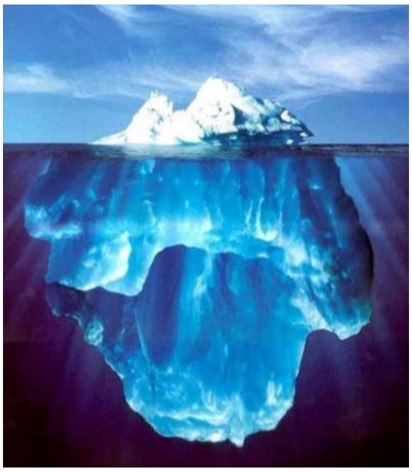


Figure 4: iceberg floating over water

For example, an iceberg (relative density, 0.9 grm/cm^3) floats in water (relative density, 1.0 grm/cm^3) in such a way that for every one part to be above water level, nine parts of the iceberg remain below water level (fig.4). If we assume the average density of the crust and the substratum to be 2.7 grm/cm^3 and 3.0 grm/cm^3 respectively, for every one part of the crust to remain above the substratum, nine parts of the crust must be in the substratum. In other words, the law of floatation demands that 'the ratio of freeboard to draught is **1:9”**. It may be pointed out that Airy did not mention the example of the floatation of iceberg. He simply maintained that the crustal parts (landmasses) were floating, like a boat, in the magma of the substratum.

In order to prove his point, the concept of floatation, Airy took several blocks of iron of the same density but unequal lengths and put them in a basin filled with mercury. The iron blocks sunk upto varying depths according to their length. The highest iron block was found to sink to the greatest depth.

This analogy of iron blocks of equal density and of varying lengths to prove the concept of floatation, it would mean that if mount Everest is 8848 Mts high, and if the ratios assumed of draught and freeboard are correct, then there is a downward projection of lighter material beneath that mountain reaching to a depth of 79,632 mts (around 80,000 mts).

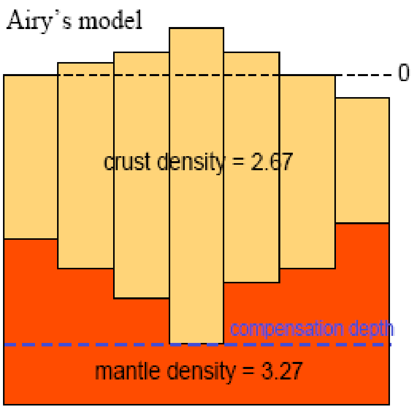


Figure 5: Different Iron blocks sinking to different depths according airy

The uplifted landmasses displace the material of the denser substratum at a considerable depth, through their long roots, so that balance is maintained. On this basis, Airy propounded the concept of ‘columns of uniform density with varying thicknesses’.

Bowie has opined that though Pratt does not believe in the law of floatation, as stated by Sir George Airy but if we look, minutely, into the concept of Pratt we certainly find the glimpse of law of floatation indirectly. Similarly, though Pratt does not believe directly in the concept of ‘root formation’ but very close perusal of his concept on isostasy, does indicate the glimpse of such idea (root formation) indirectly.

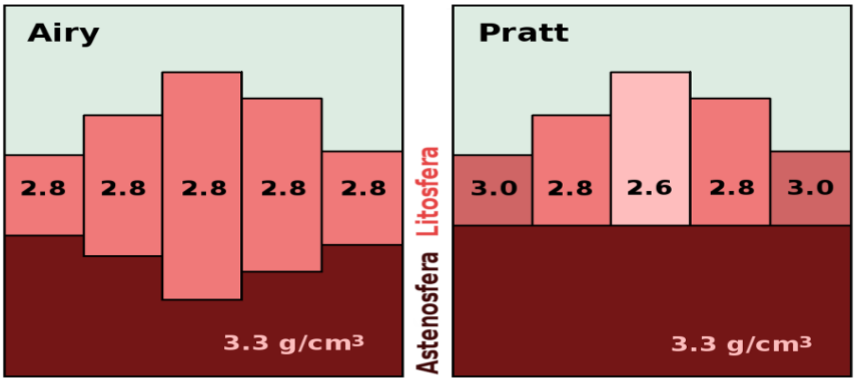
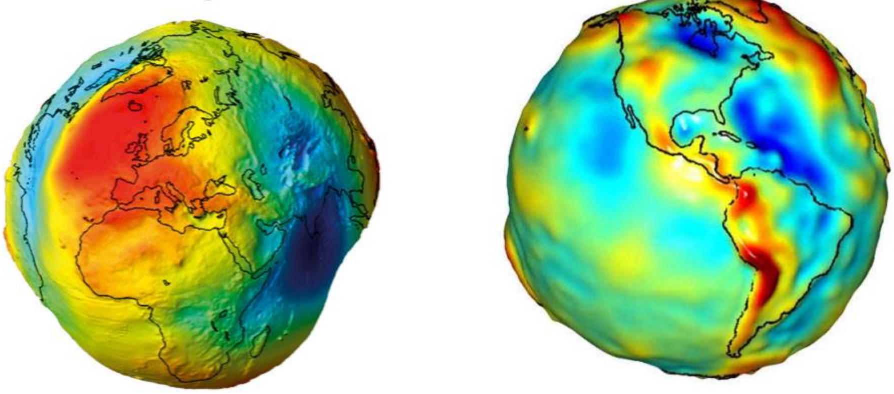


Fig 6: Difference between Airy and Pratt concepts

While making a comparative analysis of the views of Airy and Pratt on isostasy Bowie has observed that 'the fundamental difference between Airy's and Pratt's views is that the former postulated a uniform density with varying thickness, and the latter a uniform depth with varying density (Steers,1937). Fig-6 explains the fundamental difference between the concepts of Airy and Pratt on isostasy.

Shape of the Earth: Geoid

Measured figure of earth



Module 05: Continental Drift Theory

Introduction:

The movement of continents relative to each other across the earth's surface is known as Continental Drift (*Majid Hussain*). During II- World War, many scientists was discovered that the ocean floor was not a flat surface but had some unique relief features such as ridges, trenches, sea mountains and shoals etc. The most important discoveries were ridges and trenches which gave insights into natural boundaries between various lithospheric plates or tectonic plates**.** These important discoveries led to the theory of Plate Tectonics.

Plate tectonics is the large-scale movement of lithospheric plates due to forces emanating from the 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 situation, we will discuss about **'**Continental Drift Theory**'.**

Objectives:

- To understand the Continental Drift theory
- To analyse the Evidences for continental drift theory
- To understand the merits and drawbacks of Continental Drift.

5.1 CONTINENTAL DRIFT THEORY:

Alfred Wegener, the famous meteorologist polar explorer, astronomer and physicist, is said to be the real inventor of the idea of continental drift. Even though his idea of the drift of continents through sima was mooted in the year of 1912, but no attention was paid to it. A similar suggestion was made by F.B Taylor, an American geologist, in 1910. Earlier it was Abraham Ortelius, a Dutch map maker, who first proposed such a possibility of continental drift as early as 1596. Another map maker, Antonio Pellegrini, drew a map showing the three continents together. The theory introduced in two articles published by a 32-year-old German man and earned a Ph.D in astronomy from the University of Berlin in 1904. He was also fascinated with the developing fields of meteorology and climatology. The continental drift theory came into light in 1922 when he elaborated the concept in his first published book entitled "Die Entstehung Der Kontinente and Ozeane". It was revised and translated into English in 1924 as "**The Origin of Continents and Oceans"**, and expanded editions were published in 1928 and 1929.

According to Wegener's **Continental Drift Theory**, there existed one super continent (several continental masses were assembled more closely) until the late Palaeozoic era which he called as **Pangaea** (Pan= all+Gaea=Earth) which was covered on all sides by an extensive water mass or mega-ocean called the **Panthalassa** (Pan= all+ Thalassa= Ocean= all water or ocean) or the Primeval Pacific Ocean. He assumed that in the carboniferous period, the south pole was near Natal (south Africa) and the North pole was in the Pacific Ocean. In this theory, Wegener was convinced about the polar wandering. In other words, there was a considerable shift in the position of the graphical poles. The Pangaea started broken up in the carboniferous period (about 300 million years ago) as a result the Panthalassa water penetrated into the gap formed the **Tethys** sea. This means the Tethys sea divided the **Pangaea** into two huge landmasses: one is **Laurentia (Laurasia)** to the north and second is **Gondwanaland** to the south of Tethys. The southern part, the Gondwanaland consisted of Antarctica, Australia, Peninsular India, Africa and South America. The northern part of Pangaea comprised of North America, Greenland, Europe, north of the Indian subcontinent, and the remaining part of Asia, and which was known as Laurasia.

Wegener advocated this theory as he noticed that all the continents could be clubbed together like the pieces of a jigsaw puzzle to form a single land mass or super continent or Pangaea. Land mass further drifted into segments forming the seven continents in the world over a period of time. It was Alfred Wegener who first supported the theory of Continental drift. South America and Africa fit together like a jig-saw-puzzle in outline as well as rock type and geological structure.

5.2 What are the Forces behind the drifting of continents?

According to Wegener, the drift was in two directions:

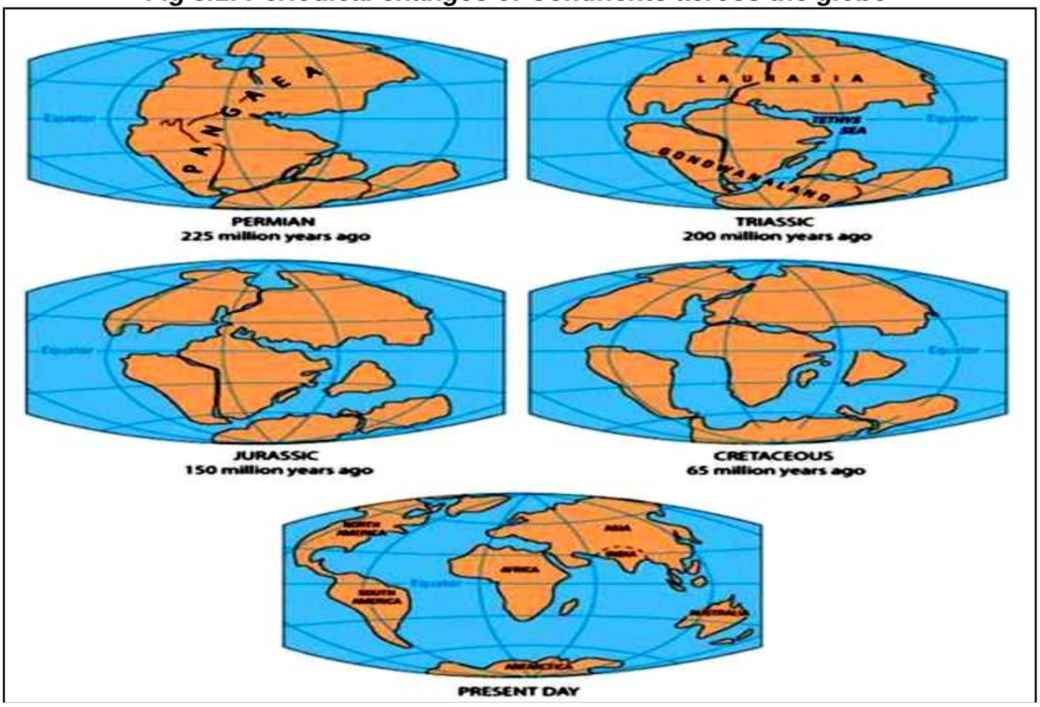
- **equator wards** due to the interaction of forces of gravity, pole-fleeing force (due to centrifugal force caused by earth's rotation) and buoyancy (*ship floats in water due to buoyant force offered by water*), and

- **westwards** due to tidal currents because of the earth's motion (earth rotates from west to east, so tidal currents act from east to west, according to Wegener).
- Wegener suggested that tidal force (gravitational pull of the moon and to a lesser extent, the sun) also played a major role.

- The polar-fleeing force relates to the rotation of the earth. 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 the equator. This increase in centrifugal force has led to pole fleeing, according to Wegener.
- Tidal force is due to the attraction of the moon and the sun that develops tides in oceanic waters (tides explained in detail in oceanography).
- According to Wegener, these forces would become effective when applied over many million years, and the drift is continuing.

The present distribution of the continents was regarded as a result of fragmentation by rifting followed by a drifting apart of the individual land mases. The drift started around 200 million years ago **(Mesozoic Era,** Triassic Period, Late Triassic Epoch**)**, and continents began to break up and drift away from one another during Carboniferous period. Since, then the pieces had moved to their present positions and are still moving.

Fig 5.1: Periodical changes of Continents across the globe



Source: U.S. Geological Survey (USGS)

It was presumed that the African and European land blocks moved together under the influence of the gravitational force; while north and south America drifted westward in response to the tidal force of the sun and the moon. As north and south America moved towards the west against the resistance of the pacific floor, their front edge would be crumpled up into great mountain ranges such as Rockies in North America and Andes in South America. The westward movement of landmasses also caused the separation of the Americas from Europe and Africa, thereby causing the formation of the Atlantic Ocean. Between these two continental land masses, certain arts of the sial lagged and formed the islands of the west indies. Wegener also attempted to explain the formation of the folded mountains with the help of the drift theory. On account of the movement of Gondwanaland towards the equator, the Alps and the Himalayas were formed in the Tertiary period in the region occupied by the Tethys sea. The supposed effects of the westerly drift of Asia resulted in the formation of gaping fissures on the Pacific floor. The island festoons are supposed to have been strips of sial that remained attached to the main land at their ends. Wegener assumed that the disruption of the Gondwanaland took place mostly during the Mesozoic era, while the westward drift of the North America occurred during the Tertiary period. However, the flight from the two poles and westerly drift by the tidal force have been disproved by the scientists as completely impossible. While Wegener was alive, scientists did not believe that the continents could move.

Although Wegener's "Continental Drift" theory was discarded, it did introduce the idea of moving continents to geosciences. And decades later, scientists would confirm some of Wegener's ideas, such as the past existence of a supercontinent joining all the world's landmasses as one. Pangaea was a supercontinent that formed roughly 200 to 250 million years ago, according to the U.S. Geological Survey (USGS) and was responsible for the fossil and rock clues that led Wegener to his theory.

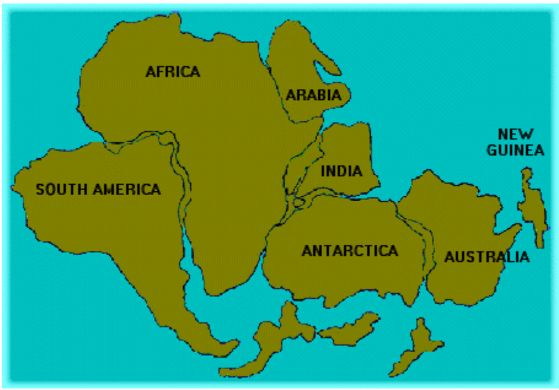
5.3. EVIDENCES OF CONTINENTAL DRIFT:

Alfred Wegner's cited various evidence in support of his theory of super continent (Pangaea) which gradually separated into Northern (Laurasia) and the Southern (Gondwanaland) landmass before finally splitting into continents of the present-day. A map of the continents inspired Wegener's quest to explain Earth's geologic history. Trained as a meteorologist, he was intrigued by the interlocking fit of Africa's and South

America's shorelines. Wegener then assembled an impressive amount of evidence to show that Earth's continents were once connected in a single supercontinent.

5.3.1 Apparent Affinity of Physical Features:

The outlines of the coasts of the Atlantic Ocean can easily be joined together. The bulge of Brazil (South America) seems to fit into the Gulf of Guinea (Africa). Wegener called it as “Jig-saw-fit” of the opposite coasts.



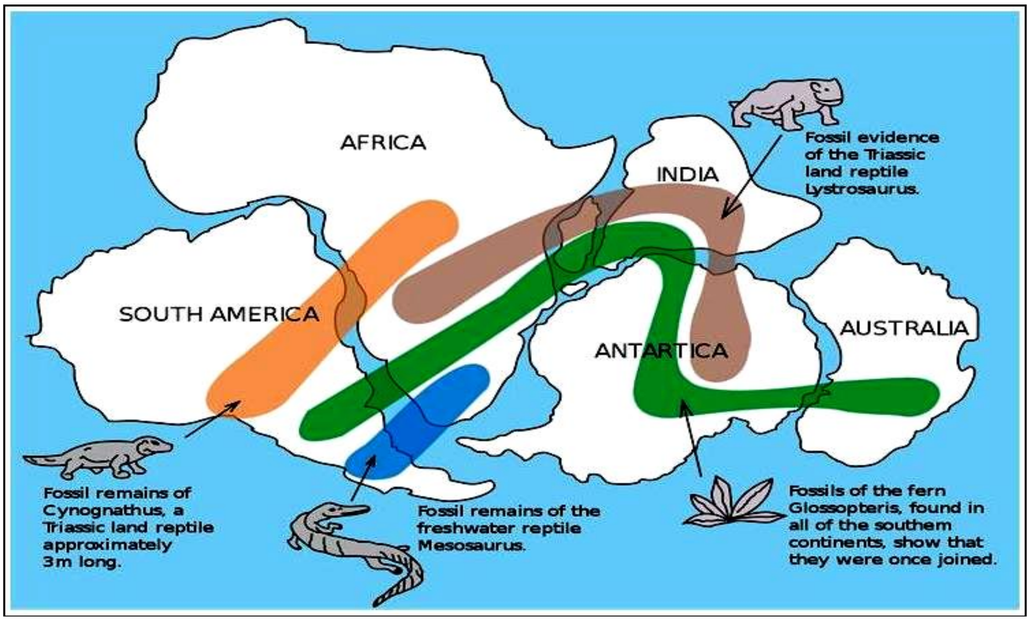
Greenland seems to fit in well with Ellesmere and Baffin islands of Canada. The west coast of India, Madagascar and Africa seem to have been joined. North and South America on one side and Africa and Europe on the other fit along the mid-Atlantic ridge. The Caledonian and Hercynian mountains of Europe and the Appalachians of USA seem to be one continuous series.

5.3.2 **Palaeontological evidences:**

Similar fossils are found on the continents on both sides of Atlantic ocean. Wegener knew that fossil plants and animals such as mesosaurs, a freshwater reptile found only South America, south Africa, India, Australia and Antarctica during the Permian period, could be found on many continents. For example, the fossils of the seed fern *Glossopteris* were too heavy to be carried so far by wind. The reptile

Mesosaurus could only swim in fresh water. It was a swimming reptile but could only swim in fresh water. *Cynognathus* and *Lystrosaurus* were land reptiles and were unable to swim. Grooves and rock deposits left by ancient glaciers are found today on different continents very close to the equator. This would indicate that the glaciers either formed in the middle of the ocean and/or covered most of the Earth.

Fig: Paleontological evidences of Continental Drift *(After Hamblin-1995)*



Source: U.S. Geological Survey (USGS)

5.3.3 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 Ghana are derived from the Brazil plateau when the two continents lay side by side

5.3.4 Tillite deposits:

These are **sedimentary rocks formed out of deposits of glaciers**. The Gondwana system of sediments are found in India, Africa, Falkland Island, Madagascar, Antarctica and Australia (all were previously part of Gondwana). Overall resemblance demonstrates that these landmasses had remarkably similar histories.

5.3.5 Polar wandering:

It means shifting of poles. The position of the poles constantly drifted (due to plate tectonics).

5.3.6 vidences from glaciation:

During the latter part of the Palaeozoic era (about 300 million years ago) glaciers covered large portion of the continents in the southern Hemisphere. The deposits left by these ancient glaciers can easily be recognised. Except of Antarctica, all the continents in the southern hemisphere show no trace of glaciation during this time.

5.3.7 **Geological Evidences:** For one, identical rocks of the same type and age are found on both sides of the Atlantic Ocean. Wegener said the rocks had formed side-by-side and that the land had since moved apart. Mountain ranges with the same rock types, structures, and ages are now on opposite sides of the Atlantic Ocean.

The Appalachians of the eastern United States and Canada, for example, are just like mountain ranges in eastern Greenland, Ireland, Great Britain, and Norway. Wegener concluded that they formed as a single mountain range that was separated as the continents drifted. Ancient fossils of the same species of extinct plants and animals are found in rocks of the same age but are on continents that are now widely separated.

5.4 Evolving theories:

When Wegener proposed continental drift, many geologists were contractionists. They thought Earth's incredible mountains were created because our planet was cooling and shrinking since its formation, Frankel said. And to account for the identical fossils discovered on continents such as South America and Africa, scientists invoked ancient land bridges, now vanished beneath the sea.

Important Theories:

i. **Polar wandering:** This Polar wandering theory very similar to Continental Drift Theory. Polar wandering is the relative movement of the earth’s crust and upper mantle with respect to the rotational poles of the earth.
ii. **Continental Drift Theory:** Continental drift refers to the movement of the continents relative to each other.
iii. **Convectional Current Theory:** Convectional current theory forms the basis of Sea floor spreading theory and Plate Tectonics.
iv. **Sea Floor Spreading Theory:** Sea floor spreading describes the movement of oceanic plates relative to one another.

v. **Plate Tectonics:** Plate tectonics is simply the movement of crustal plates relative to each other.

5.4 Criticisms on Continental Drift theory:

There are a few criticisms associated with the Continental Drift theory. Some scientists believe that the age of the earth is lesser than that is estimated. Secondly, the fossil records are also not believed to be old enough as claimed by a few. The carbon dating theory is also not widely accepted. Until 1950, this theory was not accepted. Later, in the year 1960, a group of geologists began considering the theory as the possibilities of its existence increased. There were several other factors that led to the acceptance of this theory like the fossil records. A glance into the fossil records of these continents revealed the existence of same species in their outskirts. There was also a close similarity between the mineral specimens of the break lines. Certain continents had identical species too.

Today's model of Plate tectonics derived its origin from the theory of Continental drift. The model of Plate tectonics speaks of the expansion of the ocean floors. This resulted in the movement of the plates that held the continents on their surface. The movement of the plates resulted in disruptions in the continents. This suggested that several points of the continents were subjected to smaller movements. For instance, Point Reyes located on the North California's San Andreas Fault line is proved to be moving towards the north slowly. The rate of the movement is estimated to be half an inch every year. Today, continental drift theory is accepted and taught in many schools across the globe.

Before the constriction theory, many thought that the world's formations were caused by a worldwide flood. This theory is called catastrophism, according to the USGS. Many geologists soundly denounced Wegener's theory of continental drift after he published the details. Part of the opposition was because Wegener didn't have a good model to explain how the continents moved apart.

Although Wegener's evidence was sound, most geologists at the time rejected his hypothesis of continental drift. Scientists argued that there was no way to explain how solid continents could plow through solid oceanic crust. Wegener's idea was nearly forgotten until technological advances presented even more evidence that the continents moved and gave scientists the tools to develop a mechanism for Wegener's drifting continents.

5.6 Drawbacks of Continental Drift:

There were many drawbacks for the theory of Continental Drift which was proposed by Wegener. They are;

i. The Alfred Wegener failed to explain why the drift began only in Mesozoic era and not before**;**
ii. The Continental Drift Theory doesn't take oceans into consideration;
iii. Alfred Wegener mentioned many proofs but the proofs were heavily depend on assumptions and are very general in nature;
iv. Forces like buoyancy, tidal currents and gravity are too weak to be able to move continents;
v. Modern theories accept the existence of Pangaea and related landmasses but give a very different explanation to the causes of drift.

summary:

Continental Drift theory was proposed by Alfred Wegner in 1912. Theory explained how continents shift position on Earth's surface. It also explained why look-alike animal and plant fossils, and similar rock formations, are found on different continents. According to him, the Pangaea formed with seven continents and drift started in Mesozoic Era. Though most of Wegener's observations about fossils and rocks were correct, he was outlandishly wrong on a couple of key points.

The evidences included the matching configuration of opposing continental coastlines, the similarity of geological structures on separate continental masses, the anomalous location of ancient deposits, indicating specific climatic conditions, and distribution of fossils species through time towards the equator on the spinning Earth by a centrifugal effect, while the westward movement of the continents was due to the tidal force of the Moon and Sun.

After introduced the theory many geologists were not accepted. Later on a group of geologists began considering the theory as the possibilities of its existence increased. There were several other factors that led to the acceptance of this theory like the fossil records. There were many drawbacks for the theory of Continental Drift like he failed to explain why the drift began only in Mesozoic era and not before**;** doesn't take oceans into consideration;

assumptions about the theory also very general in nature; modern theories accept the existence of Pangaea but give a very different explanation to the causes of drift.

Module 03 (a): Plate Tectonics

The rigid lithospheric slabs or rigid and solid crustal layers are technically called 'Plates'. The whole mechanism of the evolution, nature and motion of plates and resultant reaction is called "Plate Tectonics". In other words, the whole process of plate motions is referred to as plate tectonics.

The term 'plate' was first used by Tuzo Wilson, Geophysicist of Toronto University, Canada in 1965. Mckenzie and Parker discussed in detail the mechanism of plate motions on the basis of Euler's geometrical theorem in 1967. Isacks and Sykes confirmed the 'Paving Stone Hypothesis' (1967) wherein the oceanic crust was considered to be newly formed at mid-oceanic ridges and destroyed at the trenches. But the theory of plate tectonics was first published by W.J. Morgan of the Princeton University in 1968. This theory is based on the concept of 'sea floor spreading' advocated by Harry Hess and confirmed by Vine and Mathews. Now, the concept of plate tectonics theory may be considered as a revival and an improvement over Wegener's theory of continental drift.

Plate tectonics is a theory of global dynamics in which the lithosphere is believed to be broken into a series of series of separate plates that move in response to convection in the upper mantle. On their margins, considerable geologic activity, such as, sea floor spreading, volcanic eruptions, crustal deformation, mountain building and continental drift takes place.

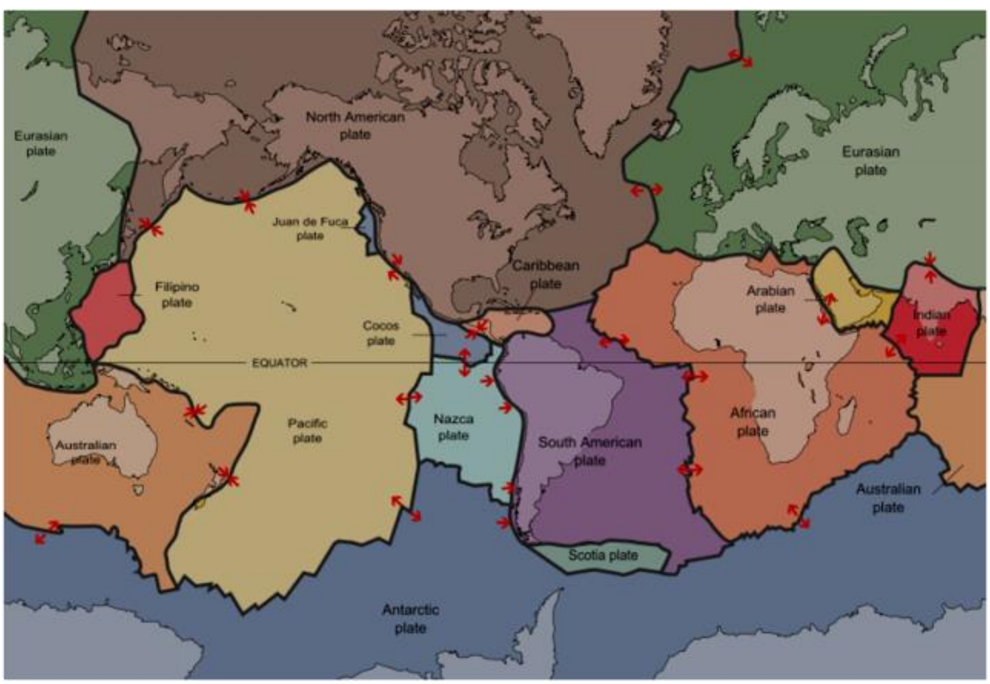


Fig 2.3.1: Distribution of Plates of Earth

In Greek language, tectonics means building or construction, or deformation of the earth's crust due to internal force. Tectonic processes include the upwelling of magma, plate movements, subduction of crust, faulting, earthquakes and vulcanicity. The rigid continental plate is a relatively 100 – 150 km thick whereas the thickness of the ocean crust ranges from 6 – 100 km. the rigid continental plates are broad segments of the lithosphere which float on the underlying asthenosphere and moves independently of other plates. The plates are drifting or moving relative to each other and in the process enormous pressure is produced along the margins of the plates which are responsible for almost all the major geomorphic and tectonic features on the crust of Earth. Le Pichon (1968) divided the earth into major and minor plates. The present shape and distribution of the continents and oceans can be described with seven major and over twenty minor lithospheric plates.

The major plates include: (i) African Plate, (ii) Pacific Plate, (iii) North American Plate, (iv) Antarctic Plate, (v) Eurasian Plate, (vi) Indo-Australian Plate, and (vii) South American Plate. The important other minor plates are: Cocos Plate, Filipino Plate, Juan de Fuca Plate, Fuji Plate, Caribbean Plate, Scotia Plate, Nazca Plate, Arabian Plate, Carolina Plate, Bismarck Plate, Philippines Plate etc. Most of the plates include both continental and oceanic crusts.

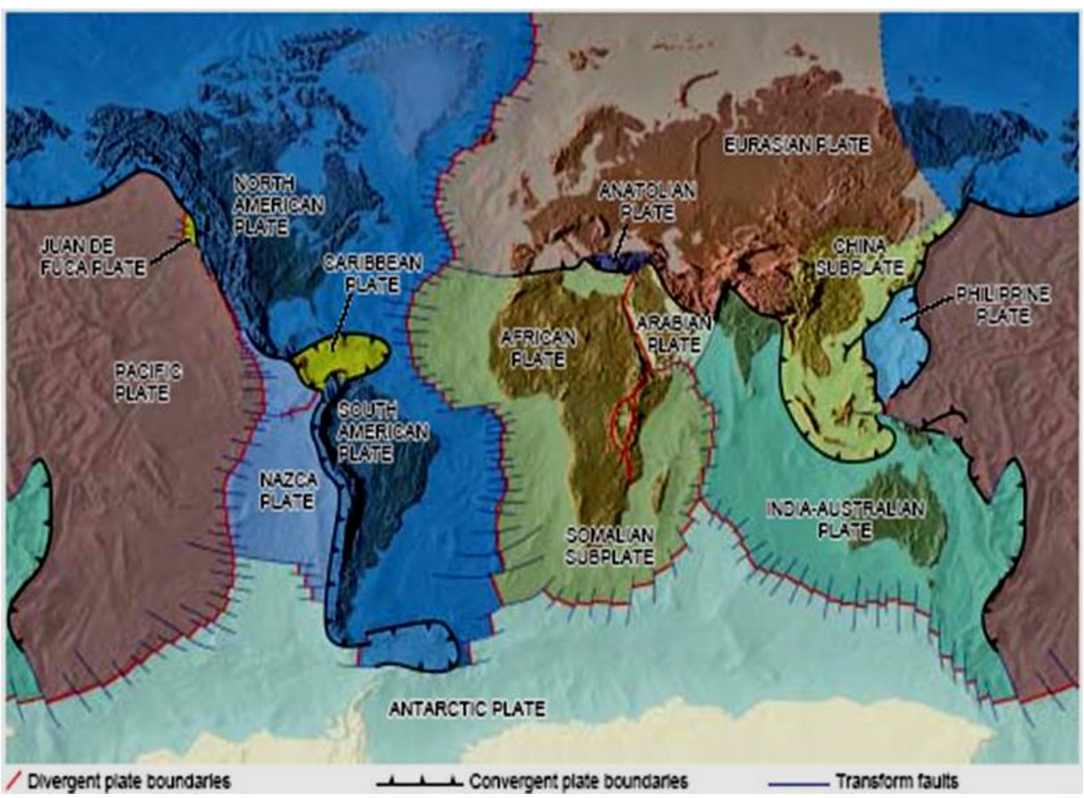
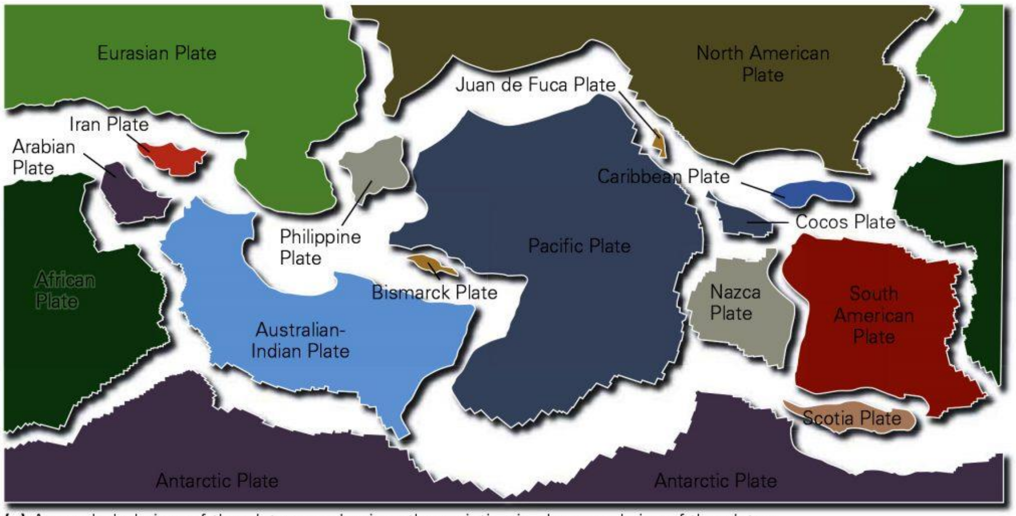


Figure 2.3.2: Major plates on the earth's crust



(c) An exploded view of the plates emphasizes the variation in shape and size of the plates.

Three types of motion are possible between the plates: (i) Divergence, (ii) Convergence, and (iii) Friction or Shearing. Tectonically plate boundaries or plate margins are most important because all tectonic activities occur along the plate margins e.g., seismic events, vulcanicity, mountain building, faulting etc. therefore, the detailed study of plate margins is not only desirable but is also necessary.

There are three basic types of identified plate boundaries and margins, on the basis of their motion: (i) Constructive plate margins (divergent plate boundaries), (ii) Destructive plate margins (convergent plate boundaries), and (iii) Conservative plate margins (Passive plate boundaries). The divergent plate boundaries are mostly seen in the deep sea along the mid oceanic ridges and the process is known as "sea floor spreading". In this sea floor spreading process new oceanic crust is constructed.

(i) Constructive plate margins (divergent plate boundaries): also called accreting plate margins. Two plates moving in opposite direction is called divergence. So, it represents a zone of divergence characterized by continuous upwelling of molten material i.e. lava, resulting into the formation of new oceanic crust. In fact, oceanic plates split apart along the mid-oceanic ridges and move in opposite directions. Thus, the mid oceanic ridge is known as ‘constructive plate margins.’

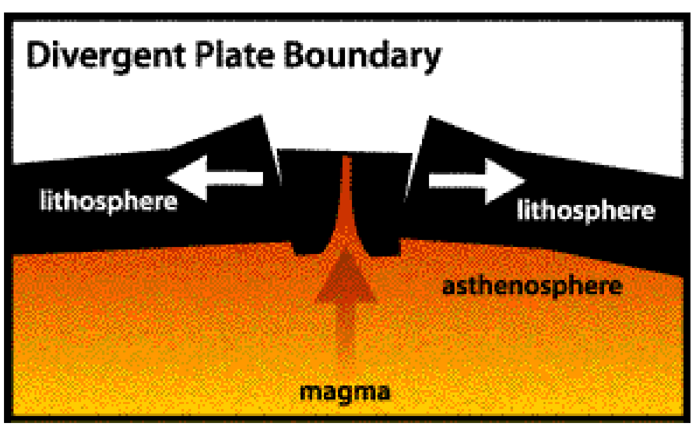


Figure 2.3.3: Divergent plate boundary

(ii) Destructive plate margins (convergent plate boundaries): also known as 'consuming plate margins.' The boundary of two or more crustal plates converge along a line is known as convergent plate boundary. Here one plate overrides the other and overridden plate is subducted or thrust into the mantle. The denser crustal plate goes down the lighter one and melts or gets destroyed into the mantle. Hence, these are called 'destructive plate margins.' The subduction plate's periodic downward movement causes earthquakes. Island arcs, trenches and deeps are resultant forms of plates convergence.

The convergent plate boundaries can further be divided into three types:

a) ***Ocean - Ocean convergent plate boundary:*** It is marked by the formation of island arcs. Example of this type of plate boundary is seen along the Japan in the Pacific Ocean.

b) ***Ocean - Continent convergent plate boundary:*** It is seen all along the Pacific Ocean boundary. This is marked by the generation of volcanic arcs on the continents. Due to this volcanic activity, the Pacific Ocean boundary is named as 'Ring of Fire'.

c) ***Continent - Continent convergent plate boundary:*** It is seen between the Indian Plate (forming Indian sub-continent) and Eurasia Plate (forming Europe and Asia). The zone is marked by the development of huge mountain ranges, e.g., Himalaya.

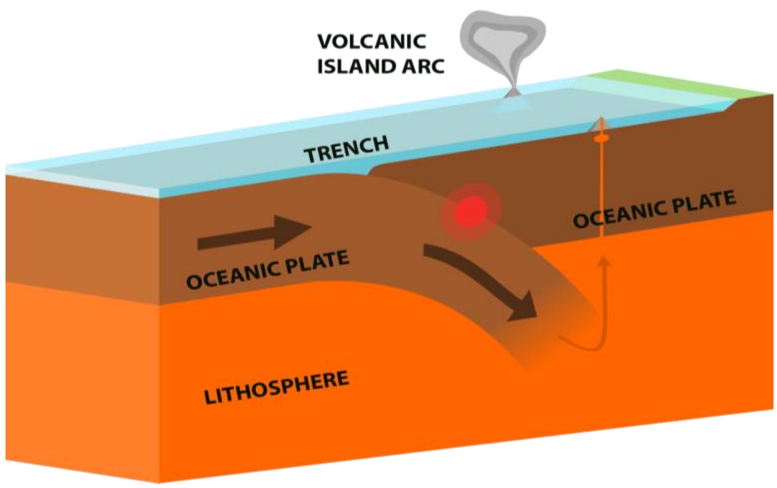
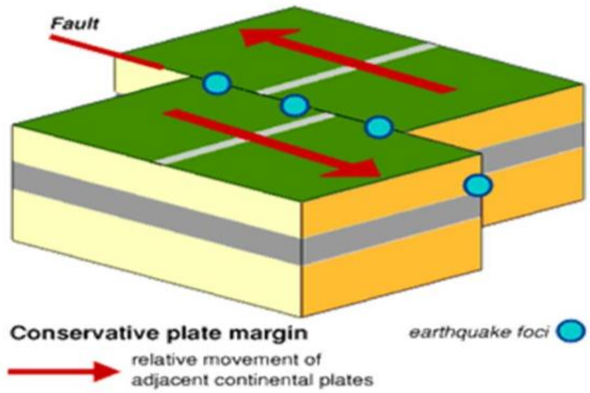


Figure 2.3.4: Convergent plate boundary

(iii) Conservative plate margins (Passive plate boundaries): these are also called as 'transform or lateral plate margins' or 'shear plate margins'. These are formed where two crustal plates pass or slide past one another along transform faults. In the case of conservative plate margins, plates neither gain nor lose surface area. But, more frequently severe earthquakes occur.

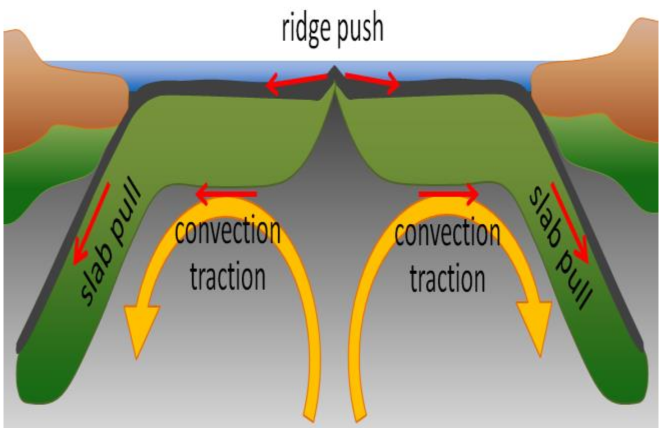


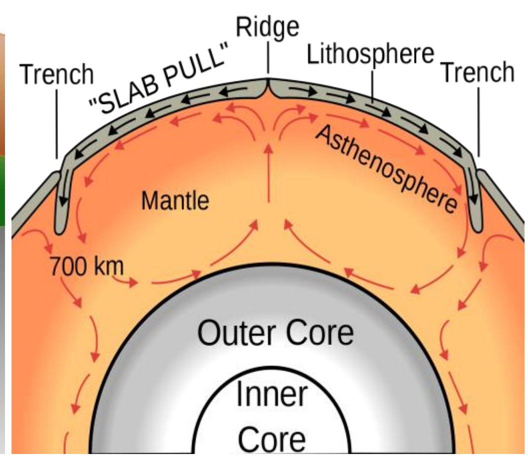
Mechanism of Plate Movement

There are various forces that act upon the plates to make them move. Three classes of possible mechanisms are namely convection current, slab pull, and ridge push. Now let us discuss about all three stages of mechanism in detail.

1. Convection Current

Convection current involves the whole mantle having large amount of radioactivity which causes huge heat concentration in the mantle. As the current ascend from below, they diverge and spread laterally along the lower part of the plates. Convection current causes the lithosphere to split and the plate may move laterally along the direction of the convection current. The high heat flow along the mid-oceanic ridges provides evidence to this process. Convectional current is only found in Asthenosphere where the size of convection cells is said to be smaller. The other type of mantle convection involves jet like plumes are called mantle plume of low density materials from the core mantle boundary. As the plume reaches the lithosphere, it spreads out laterally doming surfacial zones of the Earth and moving them along in the direction of radial flow. Mantle plumes are thought to be responsible for the initial breaking of the Pangaea.





2. Slab Pull

In the convergent boundary, the denser plate slides down the lighter plate causing subduction. The subducted portion of the plate causes slab pull. This force accounts for most of the overall forces acting on plate tectonics. Besides this, the 'ridge push' force adds about 5 to 10 per cent of the overall force for plate movement.

3. Ridge Push

The magma coming out of the mid-oceanic ridges causes the 'Ridge Push'. Before the nineties, this force was considered to be the leading contributor for moving the plates around the Earth. There have been two main models of ridge push proposed by Earth scientists, namely gravity wedging and gravity sliding. We know that mid-oceanic ridges rise thousands of metres above the ocean floor. New sea floor or oceanic plate is created along the mid-oceanic ridges, it is very hot and thin as well as much higher in elevation than the abyssal plains and trenches. The newly created plate will effectively slide down the slope and try to move towards the subduction zone causing sea floor spreading. The oceanic plate gets thicker and denser as it progresses away from the spreading centre, the ridge push force increases towards the subduction zone.

With the advancement of the Plate Tectonic Theory, the Continental Drift Theory has got enormous improvement. Continental Drift Theory says that the continents are in motion while according to plate tectonics not only the continents but the sea floor are also spreading. The generation of new oceanic crust at mid-oceanic ridges seems to be compensated by the consumption of old oceanic crust along subduction zones. So, the crustal block is to move outward from the mid-oceanic ridges.

According to Plate Tectonic Theory, it is not SIAL that is in motion, floating over SIMA but the lithospheric block (Plate) over the asthenosphere. The Continental Drift Theory talked about the gravitational and tidal forces as the chief mechanism for the movement of the continents which were largely inadequate while Plate Tectonic Theory gave five different mechanisms for the movement of the continents. The theory explains almost every aspect on the geo-tectonic features of the Earth as well as the continental drift hypothesis. Therefore, we can infer that the Plate Tectonic Theory is the latest and modern concept of Continental Drift Theory.

MODULE 3: INTERIOR OF THE EARTH

Earth's Interior: The information of the composition and internal structure of the earth has been always remained a matter of great controversy among the geologists and geo-physicists. Today, there is a lot of knowledge available about the earth's interior. The study of the earth's interior is, however, important for geographers because living on the earth's solid surface we are very aware of the materials that surround us and the processes that alter them. Deep earth mining and drilling reveal the nature of rocks deep down the surface. But as mining and drilling are not practically possible beyond a certain depth, they don't reveal much information about the earth's interior. Mponeng gold mine (deepest mine in the world) and TauTona gold mine (second deepest mine in the world) in South Africa are deepest mines reaching to a depth of only 3.9 km. And the deepest drilling is only about 12 km deep hole bored by the Soviet Union in the 1970s over the Kola Peninsula.

The main sources for the study of earth's interior includes:

1**. EVIDENCES BASED ON ARTIFICIAL SOURCES**

a. Density: The average density of Earth is about 5.52 g/cm3 and the average density of Earth's crust is about 2.7 to 3.3 g/cm3. This indicates higher density below the crust and because the acceleration due to gravity is quite uniform everywhere therefore mass is distributed uniformly in the form of concentric layers. It is estimated that the relative density of the rocks of the interior part of the earth is about 11 to 13.

b. Pressure: Pressure in itself is not responsible for the increase in density; rather the core is composed of intrinsically heavy metallic materials of high density.

c. Temperature: there is a rise of 1oC with every 32 meters of depth. This rate of increase is uniform everywhere on the earth. The temperature at the depth of 50 km should be around 1500 degree C. It is, therefore, clear that the solid layer of the Earth is a thin film over the otherwise molten material. Evidences based upon temperature indicate that middle layer exists between 1200 to 2900 km of depth. The lowest layer is considered to be 2900 to 6378 km deep.

d. Meteorites: Meteorites and Earth are born from the same nebular cloud. Thus, they are likely to have a similar internal structure. When meteoroids 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. Meteorites (hitting earth) allow us to determine the density, mineralogy and chemistry of the nickel iron core of bodies having a similar composition to that of the earth.

Table 1. ***Journey to the Center of the Earth***

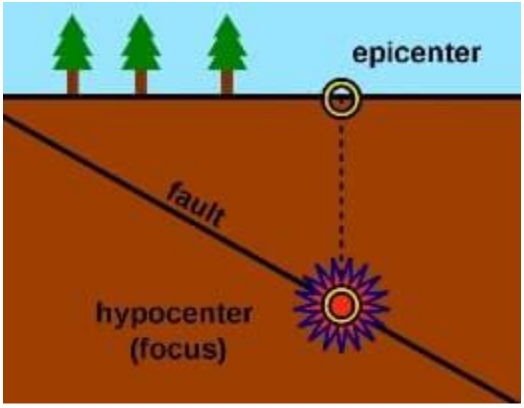
Stop Num.	Depth (km)	Scaled Depth (m) 1:1 million	Scaled Depth (m) 1:100,000	Name or Location	Rock/ Material	Density (g/cm^3)	Pres-sure (MPa)	Temp. (Deg C)
1	0	0	0	Earth's Surface	Atmosphere Sediments	0.001 1.5	0.1	~10
2	1	0.001 (1 mm)	0.01 (1 cm)	Top of "Basement"	Sed. Rocks Granitic Rk.	2.0 2.6	20	~16
3	3.6	0.0036 (3.6 mm)	0.036 (3.6 cm)	Deepest Mine	Granitic Rock	2.7	100	~50
4	10	0.01 (1 cm)	0.1 (10 cm)	Upper Crust	Granitic Rock	2.7	300	~180
5	12	0.012 (1.2 cm)	0.12 (12 cm)	Deepest Drill Hole	Granitic Rock	2.7	360	~200
6	35	0.035 (3.5 cm)	0.35 (35 cm)	Base of Crust ("Moho")	Mafic Rock Olivine-rich Rk.	3.0 3.3	1100	~600
7	100	0.1 (10 cm)	1	Base of Lithosphere	Olivine-rich Rock	3.4	3200	~1200
8	150	0.15 (15 cm)	1.5	Astheno-sphere	Olivine-rich Rock	3.35	4800	~1300
9	670	0.67 (67 cm)	6.7	Upper Mantle Transition	Fe-Mg Silicate	4.1	23800	~1700
10	2885	2.885	28.85	Core/Mantle Boundary	Fe-Mg Silicate Liquid Iron	5.6 9.9	135800	~3500
11	5155	5.155	51.55	Inner Core/Outer Core Bound.	Liquid Iron Solid Iron	12.2 12.8	329000	~5200
12	6371	6.37	63.7	Center of Earth	Solid Iron	13.1	364000	~5500

2. NATURAL SOURCES

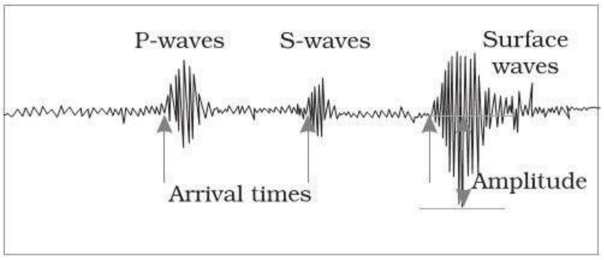
a. Vulcanicity: Some geologists on the basis of upwelling and spread of hot and liquid lava on the earth's surface during volcanic eruptions believe that there is at least a layer below the earth's surface which is in liquid state.

b. Evidences from Seismology: It has been experimentally proved that three types of waves are produced at the time of earthquake. These waves are also known as seismic waves. These include,

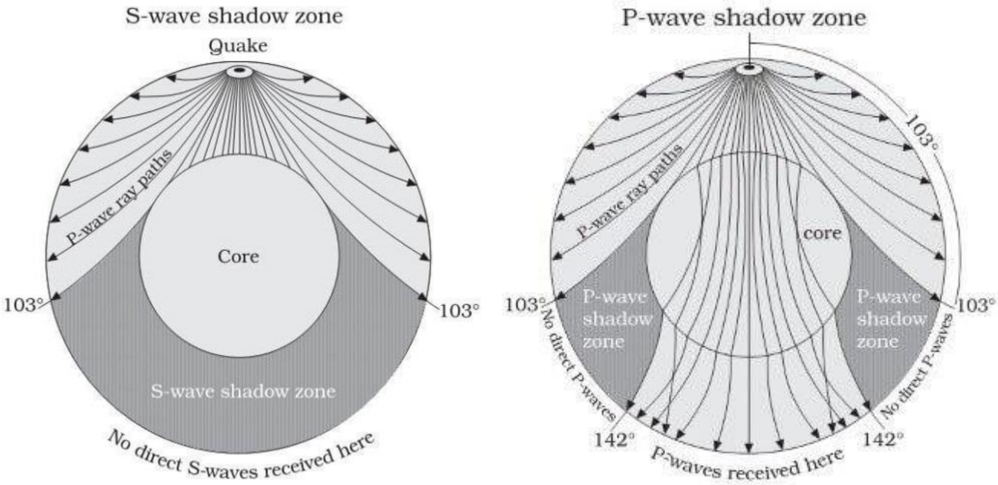
1. **Primary** (Longitudinal or Compressional or „P") waves-to and fro motion of particles in line of the propagation of the ray. These waves can pass through both the solid and the liquid medium



2. **Secondary** (transverse or distortional or S) waves-particles move at right angles to the rays. These waves cannot pass through the liquid.



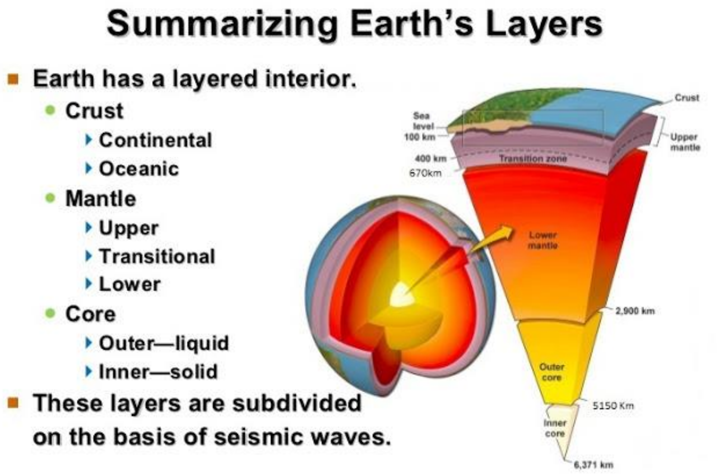
3. **Surface** (Long-Period or ‘L’) waves: Affect only the surface of the earth and covers the longest distance of all seismic waves. It has lower speed than P and S waves but is of most violent and destructive nature. These waves get reflected and refracted while passing through a body having heterogeneous composition and varying density zones at the discontinuities.



P-wave velocity depends on the elasticity, rigidity, and density of the material. By contrast, S-wave velocity depends only on the rigidity and density of the material. In most rock types P-waves travel between 1.7 and 1.8 times more quickly than S-waves; therefore, P-waves always arrive first at seismographic stations. P-waves travel by a series of compressions and expansions of the material through which they travel. The slower S-waves, also called shear waves, move like a wave in a rope. This movement makes the S-wave more destructive to structures like buildings and highway overpasses during earthquakes. Because S-waves can travel only through solids and cannot travel through Earth‟s outer core, seismologists concluded that Earth‟s outer core must be liquid or at least must have the properties of a fluid. This proves that there are various layers of different densities and medium which split the waves in many parts. It is meant that earth is made up of various shells.

STRUCTURE OF EARTH’S INTERIOR

The Crust: It is the outermost part of the earth. It is brittle in nature. The thickness of the crust varies under the oceanic and continental areas. The main thickness of oceanic crust is 5 to 8 km and that of continental is around 30 km. the continental crust is thicker in the areas of major mountain systems. It is as much as 70 km thick in the Himalayan region. It is made up of heavier rocks having density of 3 g/cm3. This type of rock found in the oceanic crust is basalt. The mean density of material in oceanic crust is 2.7g/cm3.



The Mantle: The portion of the interior beyond the crust is called the mantle. It is separated from the crust by a boundary, called Moho's discontinuity. The mantle is about 2900 km thick. It is divided into two sections: the upper mantle and the Lower mantle. These are separated by another boundary, called Repetti discontinuity, after which the rocks of the mantle become soft and pliable due to pressure and heat. The upper portion of the mantle is called asthenosphere. It is the main source of magma that finds its way to the surface during volcanic eruptions. It has a density (3.4 g/cm3) higher than the crust. The crust and upper part of mantle are called lithosphere. Its thickness ranges from 10 to 200 km. The mantle is important in many ways. It accounts for nearly half of the radius of earth, 83 per cent of its volume and 67 per cent of its mass. The dynamic processes which determine the movement of crust plates are powered by the mantle.

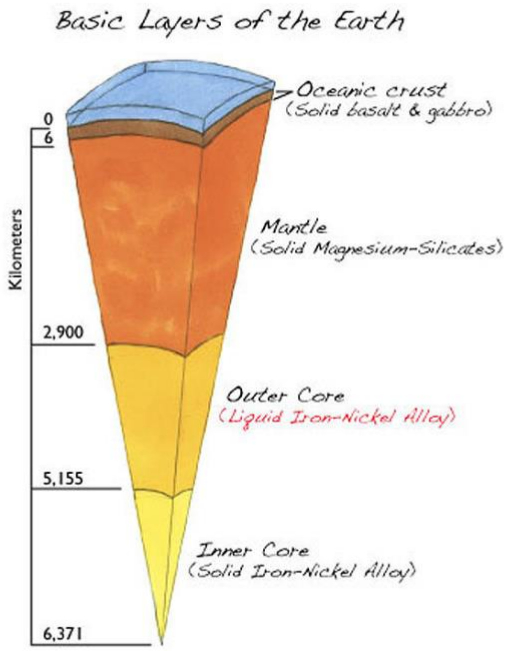
The Core: The innermost layer of the earth is called the core. Being composed of mostly metal, it is also known as the metallic core. It is separated from the mantle by a boundary called Gutenburg – Wiechert discontinuity. The core is also divided into two parts- the inner core and the outer core. The inner core is a solid and is composed of iron and nickel. The density of this core is about 13gm/cm3. The inner core is about 1300 km thick and is surrounded by an outer core of around 2080 km. The outer core appears to be molten. The inner core and the outer core are separated by Lehmann or transition discontinuity.

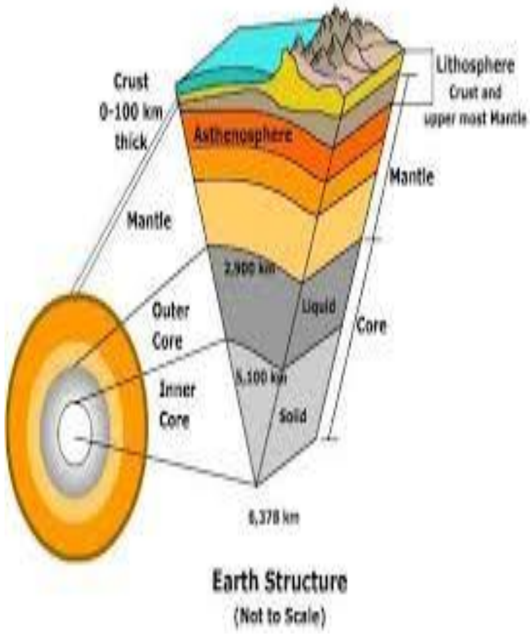
Chemically the earth can be divided into following layers:

1. SIAL

- Just below outer sedimentary cover.
- Composed mainly of granites
- Density- 2.9 g/cm3
- 50 to 300 km thick.

- Rich in silica and aluminium (Silicates mainly present are those of sodium, potassium and aluminum.)
- It forms the continental layer.
- Acidic in nature





2. SIMA

- Below SiAl
- Composed mainly of basalt
- Source of magma and lava
- Rich in silica and magnesium
- Density-2.9 to 4.7 g/cm3
- Thickness-1000 to 2000 km
- Basic in nature
- Silicate mainly present are those of magnesium, calcium and Iron.

3. NIFE

- Below SiMa
- Rich in nickel and iron
- Very high density
- Diameter of this layer-6880 km
- Indicates magnetic property of the earth's interior

MECHANICAL DIVISIONS OF EARTH

Prof. Edward Suess divides the earth‟s interior into three parts

(1) **Lithosphere**: The lithosphere is the solid layer composed of the crust and the upper mantle (40 to 100 km). Its relative density ranges from 2.75 to 2.90. It is composed of Silicon and Aluminum. It is called SIAL by Suess. This layer is mainly composed of granite. It is divided into several large fragments called plates. It moves over Asthenosphere, which is a 100 km thick layer found at the top of the lower mantle. It is a low velocity zone (that is slow speed of seismic ways in this zone) and plastic or less viscous (softer, more pliable) in nature.

(2) **Pyropsphere**: this is the middle layer, surrounds the core on all sides. Its relative density ranges from 2.9 to 4.75. It is composed of Silicon and Magnesium. Suess calls it SIMA.

(3) **Barysphere**: It comprises core. Outer layer is liquid in state where as the inner core is solid. The rocks of this layer are composed of Iron and Nickel. The relative density of these rocks is about 11 to 13. Suess calls this layer as NIFE.

DISCONTINUITIES: Many such discontinuities are expressed as follows-

1. **Gutenberg discontinuity**-Between outer liquid core and the solid mantle

2. **Mohorovicic discontinuity**-Between crust and mantle.

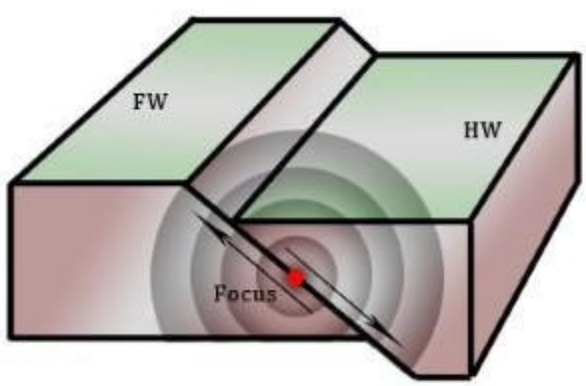
3. **Conrad discontinuity**-Between oceanic (Basaltic or SIMA layer) and continental (Granites or SIAL layer) Crust-Up to 30 − 40 km beneath the continents (greater depth in mountainous regions). 10 km deep beneath the oceans.

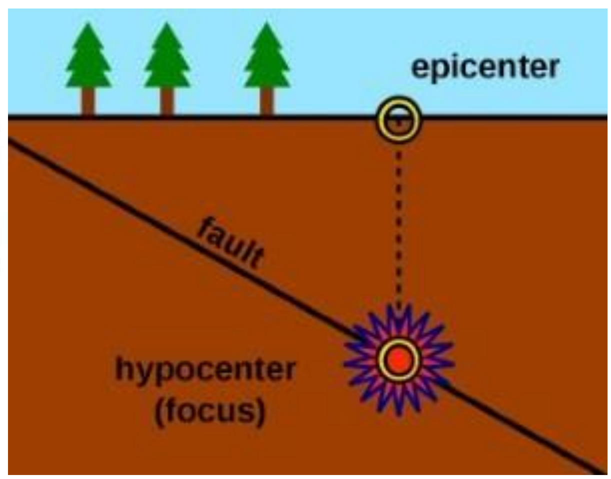
5.0 EARTHQUAKES

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

Focus and epicentre

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





The focus of an Earthquake (Eround1, via [Wikimedia Commons](#)); Epicentre (AnsateSam, via [Wikimedia Commons](#))

Foreshocks and aftershocks

- Usually, a major or even moderate earthquake of shallow focus is followed by many lesser-size earthquakes known as aftershocks.
- A mild earthquake preceding the violent shaking movement of an earthquake is known as a foreshock.

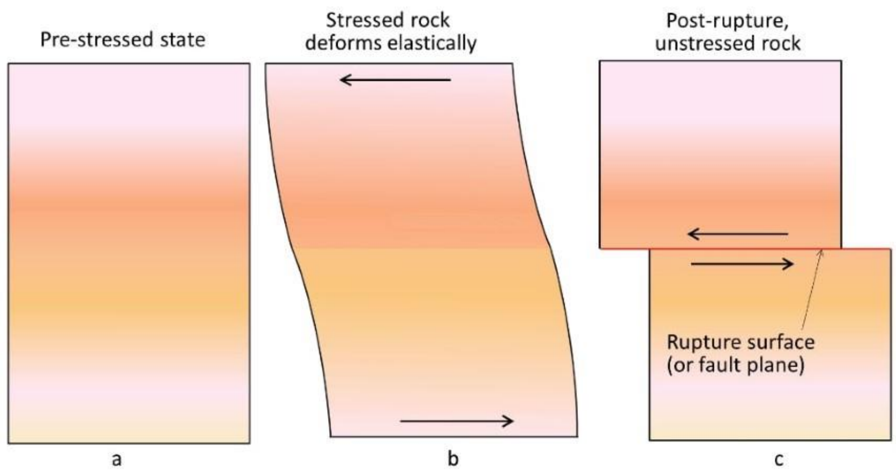
Swarms

- Large numbers of small earthquakes may occur in a region for months without a major earthquake.
- Such series of earthquakes are called earthquake swarms.
- Earthquakes associated with volcanic activity often occur in swarms.
- Earthquake swarms can serve as markers for the location of the flowing magma throughout the volcanoes.

5.1 Causes of Earthquakes

Fault Zones

- The immediate cause of most shallow earthquakes is the sudden release of stress along a fault rupture (crack) in the earth's crust.
- Sudden slipping of rock formations along fault rupturein the earth's crust happens due to the constant change in volume and density of rocks due to intense temperature and pressure in the earth's interior.



Deformation and Rupturing (Steven Earle)

- The longer the length and the wider the width of the faulted area, the larger the resulting magnitude.
- The **longest earthquake ruptures along thrust faults (convergent boundary)**are approximately 1,000 km.
- The longest earthquake ruptures on strike-slip faults (transform fault) are about half to one third as long as the lengths along the thrust fault.
- The fault ruptures along normal faults (divergent boundary) are **shorter**.

Plate tectonics

- Slipping of land along the faultline along convergent, divergent and transform boundaries cause earthquakes.
- **Reverse faults (convergent boundary) are associated with the most powerful earthquakes**, **megathrust earthquakes**, including almost **all of those of magnitude 8 or more**.
- **Megathrust earthquakes** occur at subduction zones, where one tectonic plate is forced underneath another. E.g. 2004 Indian Ocean earthquake.
- Strike-slip faults, particularly **continental transforms**, can produce major earthquakes **up to about magnitude 8**.
- **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.

- Earthquakes associated with normal faults (divergent boundary) are generally less than magnitude 7.

Volcanic activity

- Volcanic activity also can cause an earthquake, but **the earthquakes of volcanic origin are generally less severe and more limitedin extent** than those caused by fracturing of the earth's crust.
- Earthquakes in volcanic regions are caused by the consequent release of elastic strain energy both by tectonic faults and the movement of magma in volcanoes.
- Such earthquakes can serve as an **early warning of volcanic eruptions**, as during the 1980 eruption of Mount St. Helens
- 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 epicentres of most major shallow earthquakes, and many earthquake sources occur nowhere near active volcanoes.

Human Induced Earthquakes

- Human Induced Earthquakes refers to typically minor earthquakes and tremors that are caused by human activity like mining, large scale petroleum extraction, artificial lakes (reservoirs), nuclear tests etc.

Reservoir-induced seismicity

- The pressure offered by a column of water in a large and **deep** artificial lake alter stresses along an existing fault or fracture. Also, the percolation of water weakens the soil structure and lubricates the faults.
- Loading and unloading of water can significantly change the stress. This significant change in stress can lead to a sudden movement along the fault or fracture, resulting in an earthquake.
- The 6.3 magnitude 1967 **Koynanagar earthquake**occurred near the Koyna Dam reservoir in Maharashtra and claimed more than 150 lives. There have been several earthquakes of smaller magnitude since then.
- Some geologists believe that the earthquake was due to reservoir-triggered seismic activity.
- The **2008 Sichuan earthquake**, which caused approximately 68,000 deaths, is another possible example. It is believed that the construction and filling of the Zipingpu Dam may have triggered the earthquake.

5.2 Earthquakes based on the depth of focus

- Earthquakes can occur anywhere between the Earth's surface and about 700 kilometres below the surface.
- For scientific purposes, this earthquake depth range of 0 – 700 km is divided into three zones: **shallow, intermediate, and deep**.

- Shallow focus earthquakes are found within the earth's outer crustal layer, while deep focus earthquakes occur within the deeper subduction zones of the earth.
- **Shallow earthquakes are 0 – 70 km deep.**
- **Intermediate earthquakes are 70 – 300 km deep.**
- **Deep earthquakes are 300 – 700 km deep**.
- Of the total energy released in earthquakes, about **12-15percent comes from intermediate earthquakes**, about **3-5percent from deeper earthquakes** and about **70-85 percent from the shallow earthquakes**.
- A quake's destructive force depends not only on the energy released but also on location, distance from the epicentre and depth.
- On 24 August 2016, a6.2 earthquake rocked Central Italy killing about 300 people. An even bigger 6.8 hit Myanmar the same day killing just a few people.
- Italy's quake was very shallow, originating within 10 kilometres underground. By contrast, the quake in Myanmar was deeper — 84 kilometres.

5.2.1 Shallow-focus earthquake

- The great majority of earthquakes have shallow-focus. Hence, they are also called as '**crustal earthquakes**.'
- Majority of the shallow focus earthquakes are of smaller magnitudes (usual range of 1 to 5). But a few can be of a higher magnitude and can cause a great deal of destruction.
- They occur quite frequently and at random. However, as most of them are either of smaller magnitudes or occur along submarine ridges, they are often not felt.
- **Though comparatively of low magnitude, shallow focus earthquakes can cause relatively greater damage at the surface (as the whole energy is directed towards a small area) compared to their deep-focus counterparts**.

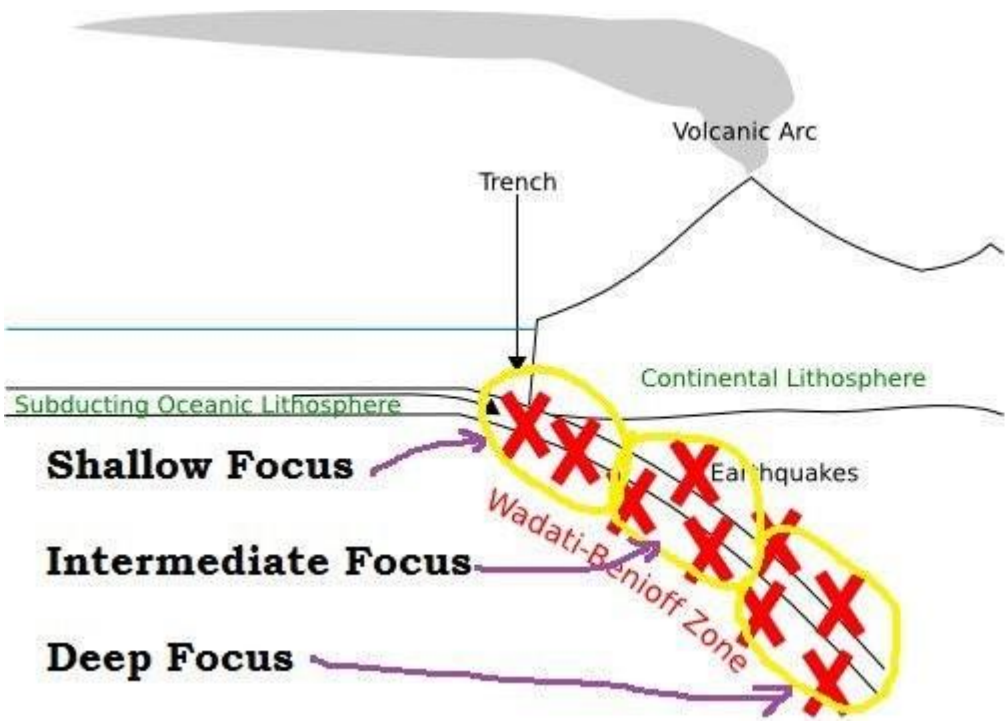
5.2.2 Deep-focus earthquake

- In general, the term "deep-focus earthquakes" is applied to earthquakes deeper than 70 km.
- The deeper-focus earthquakes commonly occur in patterns called **Benioff zones** that dip into the Earth, indicating the presence of a **subducting slab (zone of subduction)**.
- Hence, they are also are known as **intraplate earthquakes** (triggered by the collision between plates).
- They happen as **huge quakes with larger magnitudes**(usual range of 6 to 8), as a great deal of energy is released with the forceful collision of the plates.
- **But the earthquakes alonemay not cause much destruction as the foci of the quakes lie at great depths and the energy of the quakes dissipates over a wide area**.

- The strongest deep-focus earthquake in seismic record was the magnitude 8.3 Okhotsk Sea earthquake that occurred at a depth of 609 km in 2013.
- The deepest earthquake ever recorded was a 4.2 earthquake in Vanuatu at a depth of 735.8 km in 2004.

5.2.3 Wadati–Benioff zone: Earthquakes along the Convergent boundary

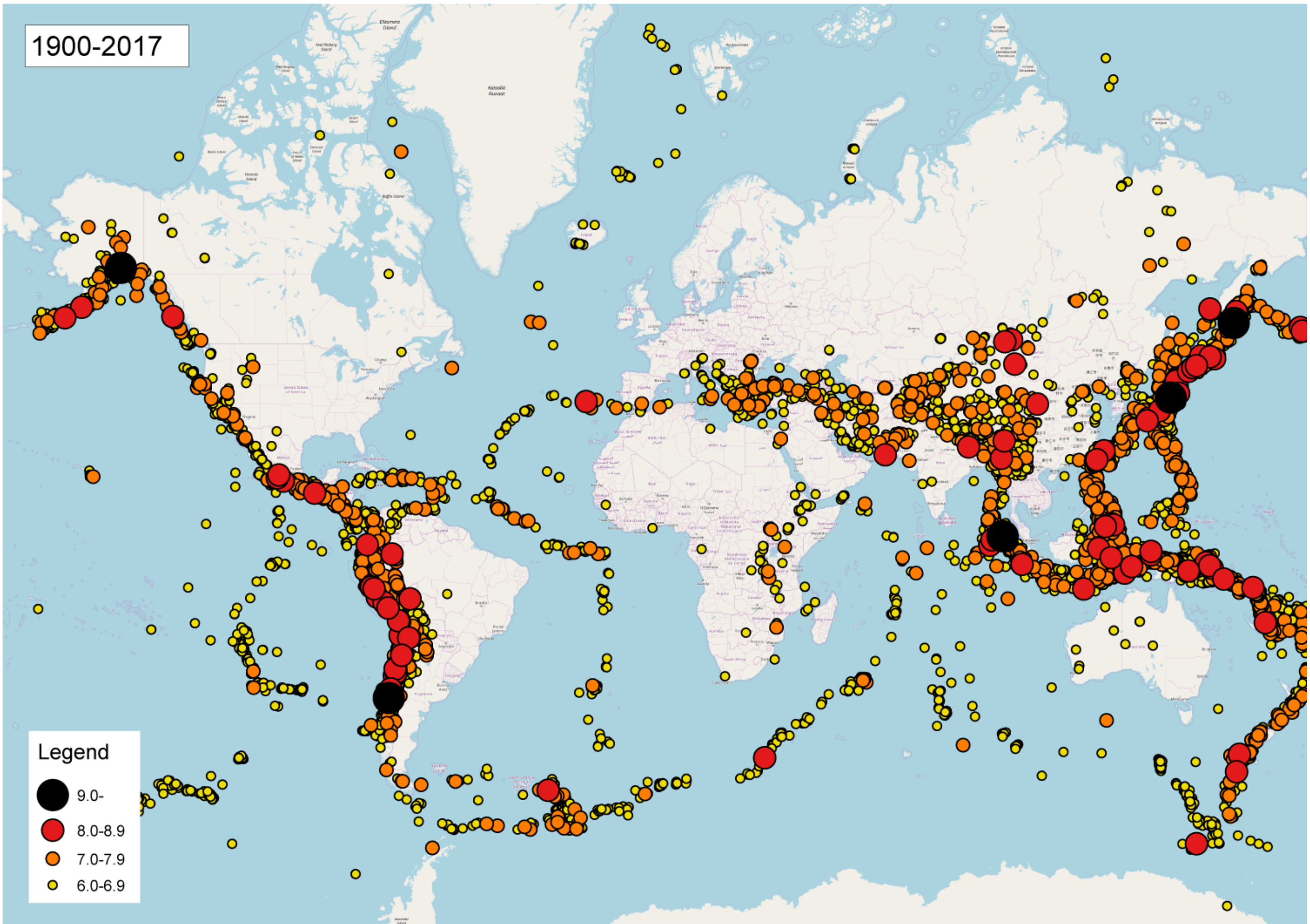
- Wadati Benioff zone is a zone of subduction along which earthquakes are common.**The most powerful earthquakes occur along this zone**(most powerful earthquakes occur along the convergent boundary).
- Differential motion along the zone produces numerous earthquakes, the foci of which may be as deep as about 700 kilometres.
- **Wadati–Benioff zones** can be produced by slip along the **subduction thrust fault (Himalayan Region – C-C convergent boundary)** or **slip on faults within the downgoing plate (O-O and C-O convergent boundary)**.



5.3 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 many 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.
- 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**.



Distribution of Earthquakes

5.4 Richter magnitude scale

- Charles F. Richter developed the Richter magnitude scale (M_L) for measuring the strength (amount of energy released) of earthquakes in 1930s.
- Because of the various shortcomings of the $M_L$scale, seismologists now use moment magnitude scale (M_w).
- Both the scales are logarithmic and are scaled to have **roughly comparable numeric values**.
- Moment magnitude scale M_w scale is now generally referred to as the Richter scale.
- Under the Richter magnitude scale, an **increase of one step corresponds to about32 times increase in the amount of energy released**, and **an increase of two steps corresponds to 1,000 times increase in energy**.
- Thus, **an earthquake of M_w of 7.0 releases about 32 times as much energy as one of 6.0 and nearly 1,000 times (~ 32 X 32) one of 5.0**.
- Richter scale is only effective for regional earthquakes no greater than M_5. Moment magnitude scale is more effective for large earthquakes.

Magnitude	Description	Average earthquake effects	Frequency of occurrence
1.0–1.9	Micro	• Microearthquakes, not felt, or felt rarely. • They are recorded by seismographs.	Several million per year
2.0–2.9	Minor	• Felt slightly by some people. • No damage to buildings.	Over one million per year
3.0–3.9		• Often felt by people, but very rarely causes damage. • Shaking of indoor objects can be noticeable.	Over 100,000 per year
4.0–4.9	Light	• Noticeable shaking of indoor objects. • They are felt by most people in the affected area. • Slightly felt outside. • Generally, causes none to minimal damage. • Some objects may fall off shelves or be knocked over.	10,000 to 15,000 per year
5.0–5.9	Moderate	• Can cause damage of varying severity to poorly constructed buildings. • At most, none to slight damage to all other buildings. • Felt by everyone.	1,000 to 1,500 per year
6.0–6.9	**Strong**	• Damage to a moderate number of well-built structures in populated areas. • Earthquake-resistant structures survive with slight to moderate damage. • Poorly designed structures receive moderate to severe damage. • Felt in wider areas; up to hundreds of kilometres from the epicentre. • Strong to violent shaking in the epicentral area.	100 to 150 per year • 2011 Christchurch earthquake (6.2)

7.0–7.9	**Major**	• Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great distances with major damage mostly limited to 250 km from epicentre.	10 to 20 per year • **1819 Rann of Kutch earthquake (7.7–8.2)** • **2001 Gujarat earthquake (7.7)**
8.0–8.9	**Great**	• Major damage to buildings, structures likely to be destroyed. • Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. • Damaging in large areas. • Felt in extremely large regions.	One per year • 1556 Shaanxi earthquake (8.0) • 1950 Assam–Tibet earthquake (8.6) • 2008 Sichuan earthquake (8.0) • 2010 Chile earthquake (8.8)
9.0 and greater		• At or near total destruction – severe damage or collapse to all buildings. • Heavy damage and shaking extends to distant locations. • Permanent changes in ground topography.	One per 10 to 50 years • **1960 Valdivia earthquake, Chile (9.4–9.6)** • **1964 Alaska earthquake (9.2)** • **2004 Indian Ocean earthquake (9.1–9.3)** • **2011 Tōhoku earthquake, Japan (9.1)**

Based on U.S. Geological Survey documents

5.4.1.1 Most powerful earthquakes ever recorded

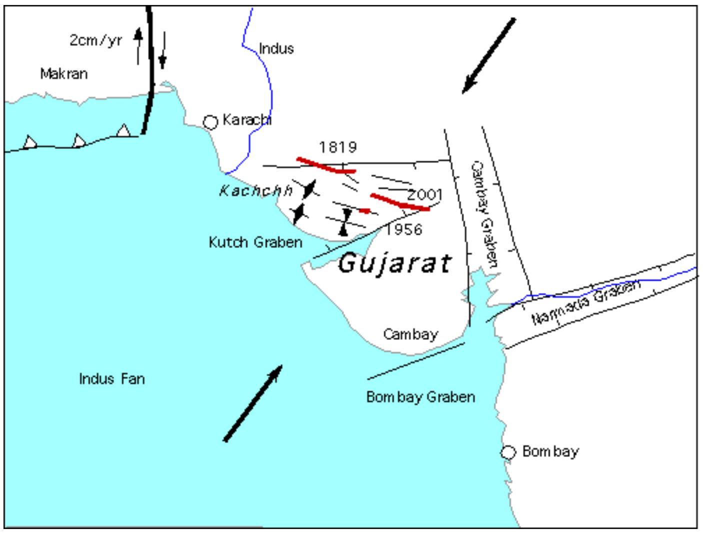
	Event	M_w	Focus	
1	1960 Valdivia earthquake	9.4–9.6	33 km	• Undersea megathrust earthquake • **Most powerful earthquake ever recorded** • The resulting tsunami affected the entire Pacific Rim killing 1,000–7,000 people.

2	1964 Alaska earthquake	9.2	25 km	• Collapsing structures and tsunamis resulted in 100+ deaths.
3	2004 Indian Ocean earthquake	9.1–9.3	30 km	• Undersea megathrust earthquake • Caused by a rupture along the fault between the **Burma Plate** and **the Indian Plate**. • A series of large tsunamis up to 30 metres high were created. • The earthquake and the resulting tsunami caused the 6th deadliest natural disaster in recorded history with more than 227,000 causalities in 14 countries. • The shift of mass and the massive release of energy slightly altered the Earth's rotation.
4	2011 Tōhoku earthquake	9.1	30 km	• Undersea megathrust earthquake • Most powerful earthquake ever recorded in Japan • The earthquake triggered powerful tsunami waves • 15,896 causalities • Caused **Fukushima Daiichi nuclear disaster**

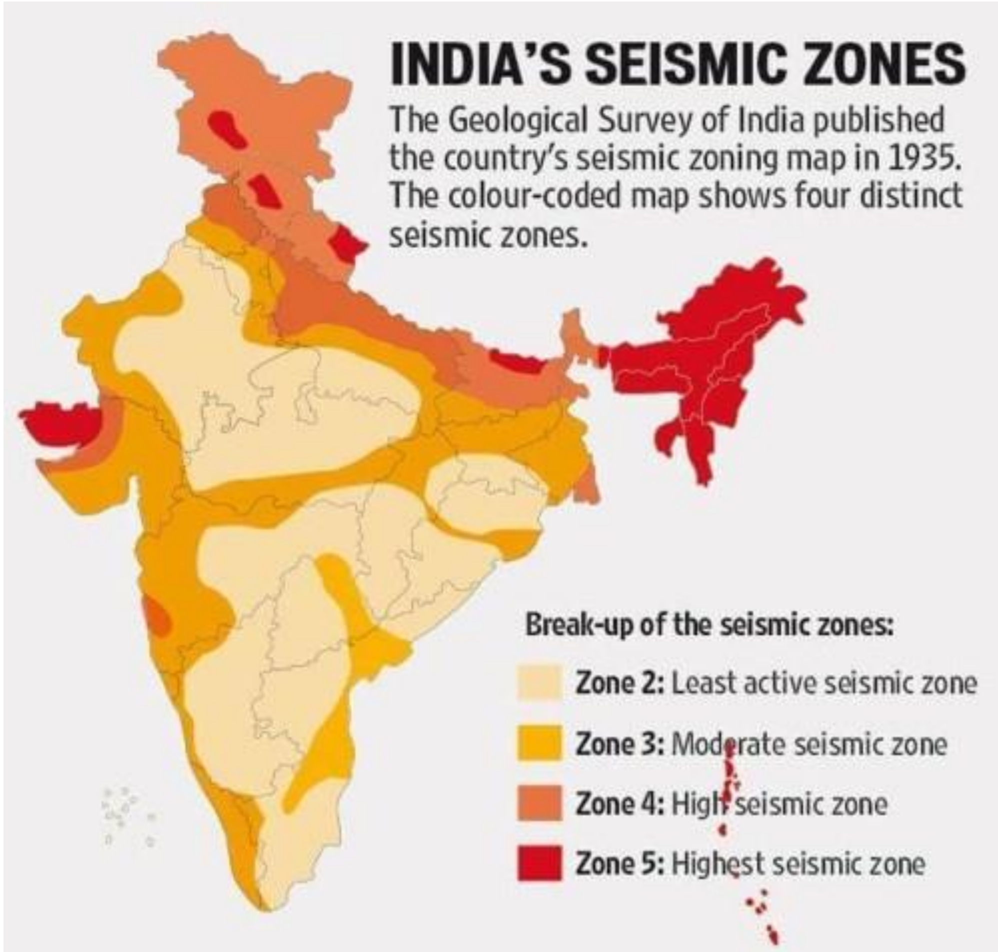
5.4.1.2 Notable earthquakes

Event	Magnitude	Notes
1556 Shaanxi earthquake	8.0	**Deadliest earthquake** with 8,00,000+ fatalities Most of the deaths were caused due to the collapse of artificial caves carved into the loess cliffs
2011 Tōhoku earthquake and tsunami	9.1	**Costliest earthquake** that caused damage to property worth $250 billion
1819 Rann of Kutch earthquake	7.7 to 8.2	It triggered a tsunami and caused more than 1000 deaths The earthquake caused an area of subsidence that formed the **Sindri Lake** and a local zone of uplift to the north about 80 km long, 6 km wide and 6 m high that dammed the several rivers. This natural dam was known as the **Allah Bund** (Dam of God).
2001 Gujarat earthquake (Focus: 24 km)	7.7	The earthquake killed between 13000 and 20000 people

- The Gujarat quake occurred 400 km to the south-east of the tectonic boundary separating Indian Plate and the Eurasian Plate.
- The current tectonics is governed by the effects of the continuing continental collision along this boundary.
- The collision has reactivated the original rift faults and development of new thrust faults in the region.
- The pattern of uplift and subsidence associated with the 1819 Rann of Kutch earthquake is consistent with reactivation of such faults.
- The area saw many minor earthquakes in the 20th Century including the 2001 earthquake.



5.4.1.3 Earthquake zones of India



Earthquake zones of India (Source)

- The latest seismic zone map prepared by the National Disaster Management Authority reveals that **nearly 59% of India's land area is prone to moderate or severe earthquakes**.
- This earthquake zoning map divides India into five different zones of earthquake intensity and highlights the location that falls under them.

5.5 Effects of Earthquakes

5.5.1 Shaking and ground rupture

- Shaking and ground rupture result in severe damage to buildings and other rigid structures.
- Ground rupture (crack along the fault) is a major risk for large engineering structures such as dams, bridges and nuclear power stations.

5.5.2 Landslides and avalanches

- Earthquakes, along with severe storms, volcanic activity, coastal wave attack, and wildfires, can produce slope instability leading to landslides, a major geological hazard.

5.5.3 Fires

- Earthquakes can cause fires by damaging electrical power or gas lines.
- More deaths in the 1906 San Francisco earthquake were caused by fire than by the earthquake itself.

5.5.4 Soil liquefaction

- Soil liquefaction occurs when water-saturated soil temporarily loses its strength and transforms from a solid to a liquid. Soil liquefaction may cause rigid structures, like buildings and bridges, to tilt or sink.

5.5.5 Tsunami

- Megathrust earthquakes can produce long-wavelength, long-period sea waves due to abrupt movement of large volumes of water.

5.5.6 Floods

- Floods may be secondary effects of earthquakes if dams are damaged.
- Earthquakes may cause landslips to dam rivers, which collapse and cause floods.

5.5.7 Tsunami

- Tsunami is a Japanese word for "**Harbour wave**". A tsunami is a series of **very long-wavelength**waves in large water bodies like seas or large lakes caused by a majordisturbance above or below the water surface or due to the displacement of a large volume of water.
- They are sometimes referred to as tidal waves because of **long wavelengths**, although the attractions of the Moon and Sun play no role in their formation.
- Earthquakes (e.g. 2004 Indian Ocean Tsunami), volcanic eruptions (e.g. tsunami caused by the violent eruption of Krakatoa in 1883), landslides (tsunami caused by the collapse of a section of Anak Krakatoa in 2018), underwater explosions, meteorite impacts, etc. have the potential to generate a tsunami.
- Subduction zones off Chile, Nicaragua, Mexico and Indonesia have created killer tsunamis.
- The Pacific among the oceans has witnessed the most number of tsunamis (over 790 since 1990).

5.5.7.1 Mechanism of tsunami waves

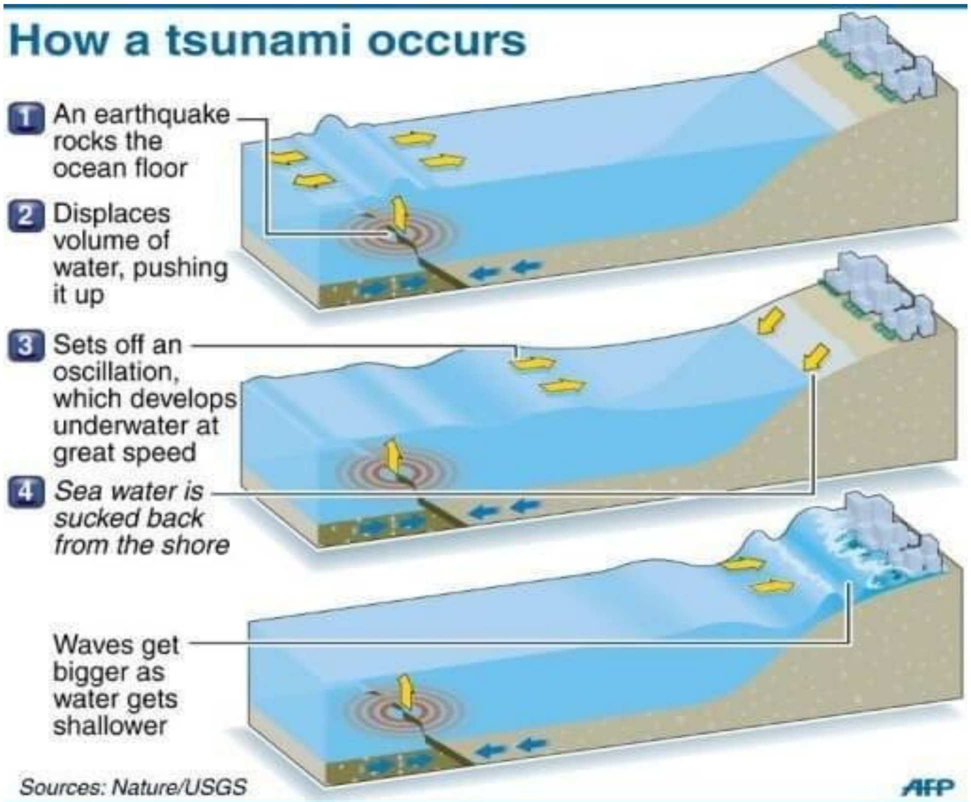
Disturbance

- Megathrust earthquakes cause a sudden displacement in a seabed sufficient to cause the sudden raising of a large body of water.

- As the subducting plate plunges beneath the less dense plate, stresses build up, the locked zone between the plates give way abruptly, and the parts of the oceanic crust is then upthrust resulting in the displacement of a large column of water vertically.
- The tsunami on December 26, 2004, was caused after an earthquake displaced the seabed off the coast of Sumatra, Indonesia.
- 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.
- Most destructive tsunamis can be caused due to the fall of extra-terrestrial objects on to the earth.

Propagation of the waves

- Gravity acts to return the sea surface to its original shape.
- The ripples then race outward, and a tsunami is caused.
- 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 the decrease in speed, the 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 the 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.



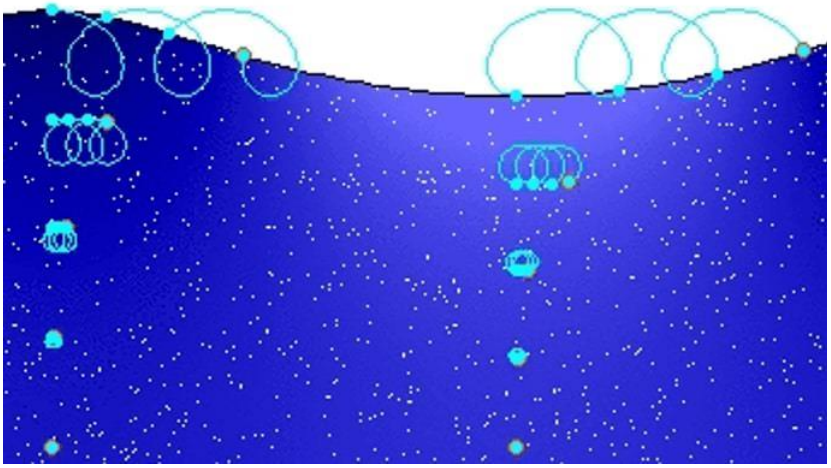
Properties of Tsunami Waves

Basics

- 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 the time interval between two successive wave crests or troughs.
- Wavelength: It is the horizontal distance between two successive crests.
- Wave frequency: It is the number of waves passing a given point during a one second time interval.

Normal 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 normal wind-generated waves do not move, but the **wave trains move ahead**.
- The motion of normal waves seldom affects the stagnant deep bottom water of the oceans.



Wind generated wave motion

- 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.
- As a wave approaches the beach, it slows down.And, when the depth of water is less than half the wavelength of the wave, the wave breaks (dies).

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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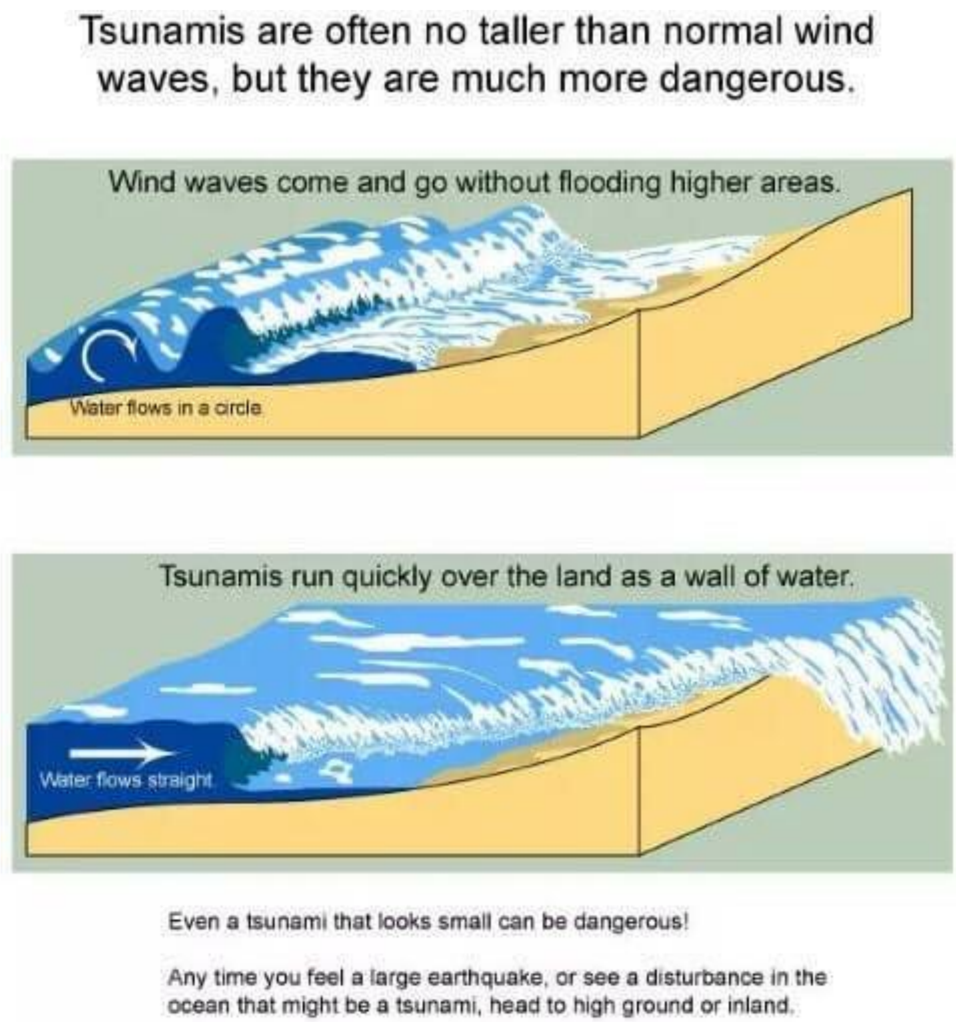


- Tsunamis are a series of waves of very, very long wavelengths and period.
- Tsunamis are different from the wind-generated waves (period of five to twenty seconds).
- Tsunamis behave as **shallow-water waves** because of their long wavelengths. They have a period in the range of ten minutes to two 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.
- **They travel at high speeds in deep waters,and their speed falls when they hit shallow waters**.
- A tsunami that occurs 1000 metres deep in water has a speed of more about 350 km per hour. At 6000 m, it can travel at speeds about 850 km per hour.
- **Tsunami waves are not noticed by ships far out at sea**.
- 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 closed harbours and inlets (funnelling effect).

2004 Indian Ocean Tsunami

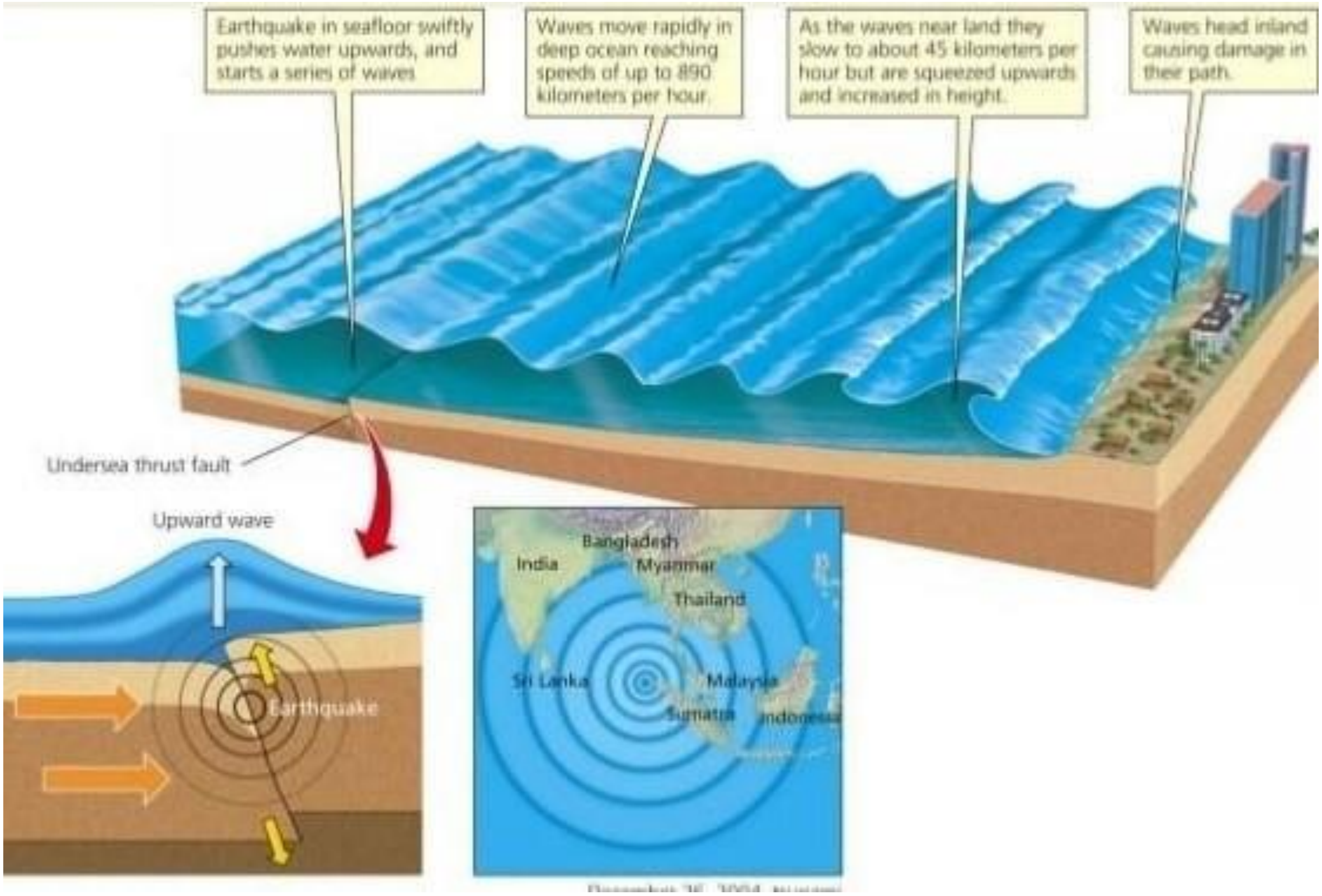
- Tsunami or the Harbour wave struck havoc in the Indian Ocean on the 26th of December 2004.
- The wave was the result of an earthquake that had its epicentre near the western boundary of Sumatra.
- The magnitude of the earthquake was 9.0 on the Richter scale.

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 downward 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 a tsunami.

Tsunami waves

- Tsunami travelled 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 epicentre from Sumatra towards the Andaman Islands and Sri Lanka, the **wavelength 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 travelled 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.



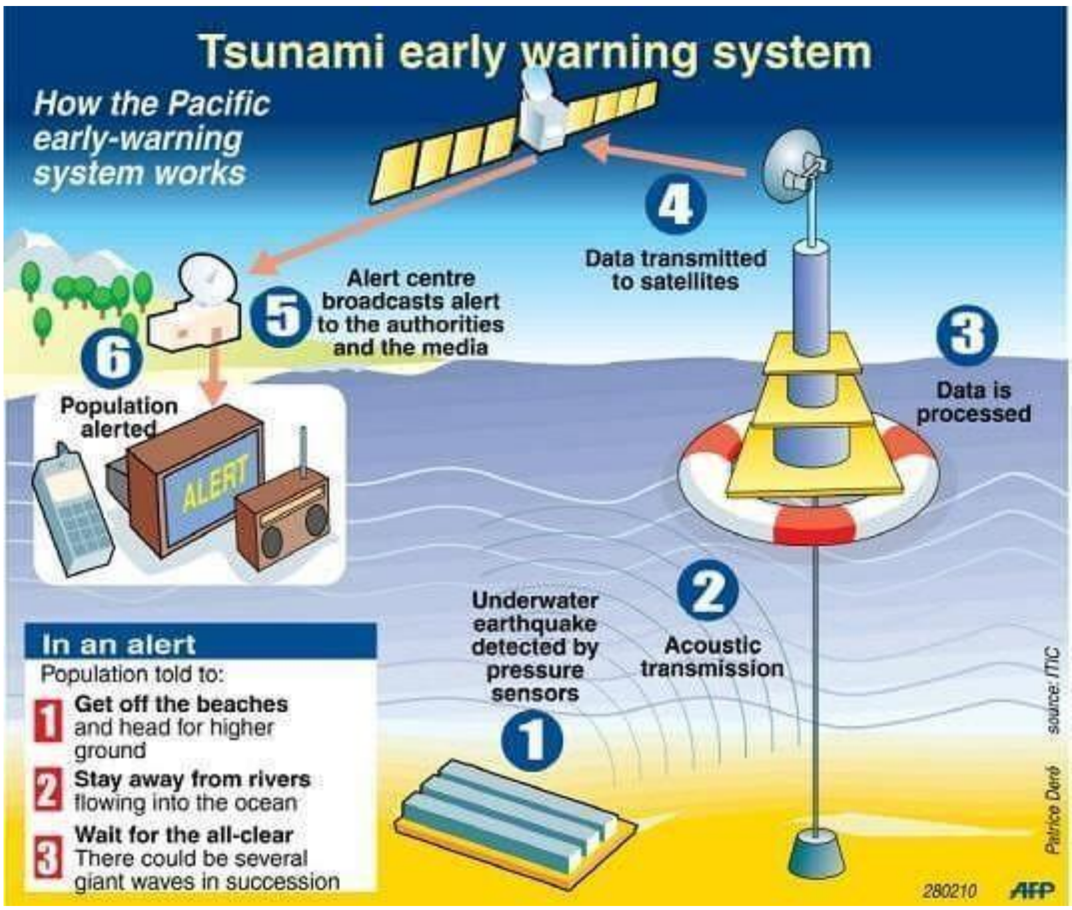
Shifts in Geography

- 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.

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 the 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**monitor data.
- Based on the data, warnings are issued.



5.5.7.2 India's preparedness

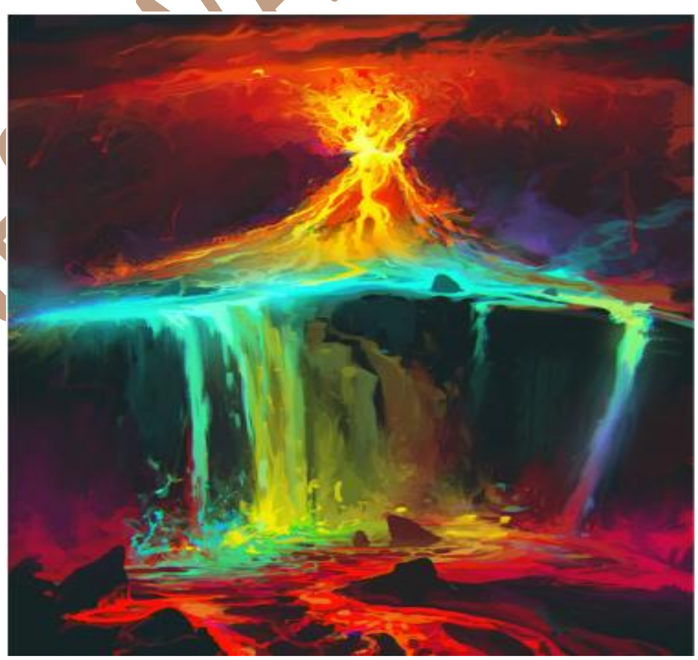
- The Deep Ocean Assessment and Reporting System (DOARS) was set up in the Indian Ocean post-2004.
- The Indian government plans to set up a network with Indonesia, Myanmar and Thailand etc.
- A **National Tsunami Early Warning Centre**, which can detect earthquakes of more than 6magnitude in the Indian 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 analyse the seismic data following an earthquake.

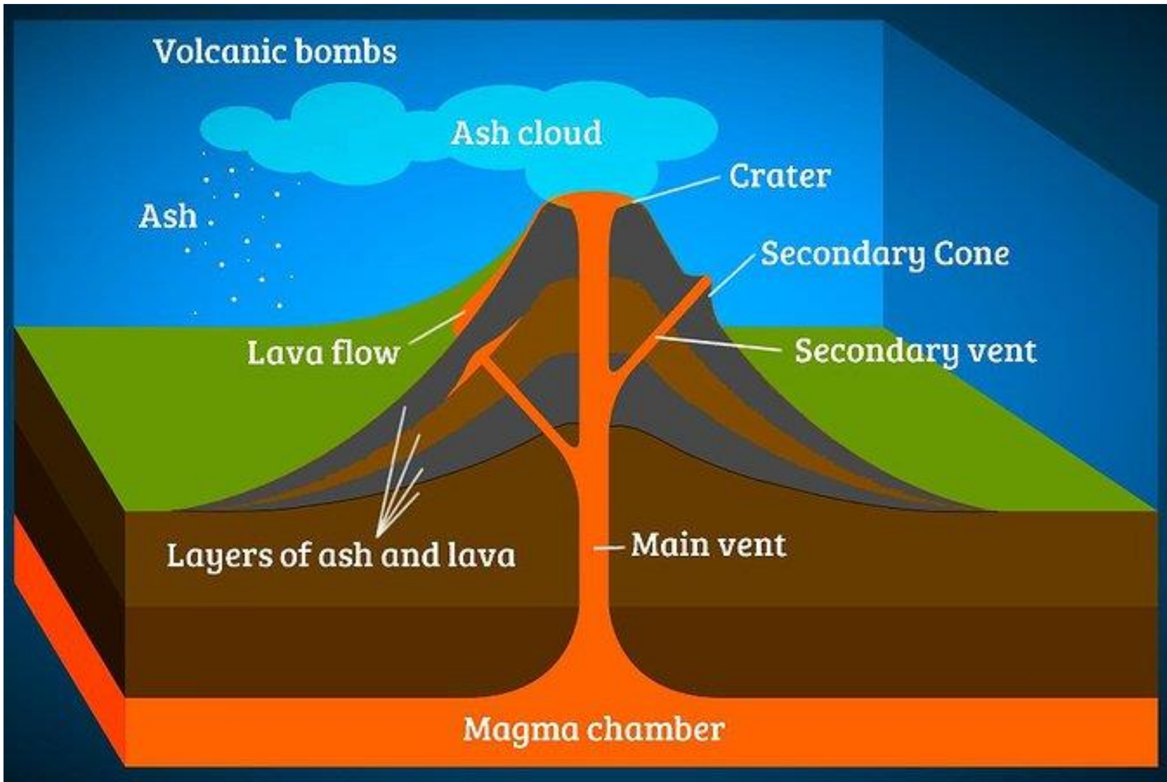
Volcanism

Scientists estimate that at least 500 million of the total world population is at risk from volcanoes. Millions of people are vulnerable to the effects of dangerous eruptions. Therefore, it is important to improve our understanding of the volcanoes and how they work. Study of volcanos is known as **Volcanology** and scientist studying volcanoes are called **volcanologist**. Volcanology also improves our understanding of Earth's interior.

The term **volcano** is derived from 'Vulcan', the Roman God of fire and metalwork. Volcano may be defined as any landform that releases lava, gas or ashes or has done so in the past (Fletcher, 2011). The geologic processes that give rise to volcanoes and volcanic rocks are collectively known as **volcanism**. Volcanism is the phenomenon of eruption of molten rock (magma) onto the surface of the Earth or a solid-surface planet or moon, where lava, pyroclastics and volcanic gases erupt through a break in the surface called a vent. Volcanoes occur not only on the Earth but on other planets too. About 1500 volcanoes are believed to be active on Earth's surface.

- A volcano is a vent or a fissure in the crust from which lava (molten rock), ash, gases, rock fragments erupt from a magma chamber below the surface.
- Volcanism is one of the endogenetic processes capable of rendering sudden and massive changes in the surface features of the Earth.
- It represents processes and features related to the movement and solidification of magma both within the crust and on the surface. Surface processes include the formation of volcanoes.
- Volcanism is the phenomenon of eruption of molten rock, pyroclastics and volcanic gases to the surface through a vent.





Causes of Volcanism

- There is a **huge temperature difference** between the inner layers and the outer layers of the earth due to the differential amount of radioactivity.
- This temperature difference gives rise to **convectional currents** in the mantle.
- The convection currents in the mantle create convergent and divergent boundaries (weak zones).
- At the divergent boundary, molten, semi-molten and sometimes gaseous material appears on earth at the first available opportunity.
- The earthquakes here may expose fault zones through which magma may escape (**fissure type volcano**).
- At the convergent boundary, the subduction of denser plate creates magma at high pressure which will es- cape to the surface in the form of violent eruptions.

Lava types

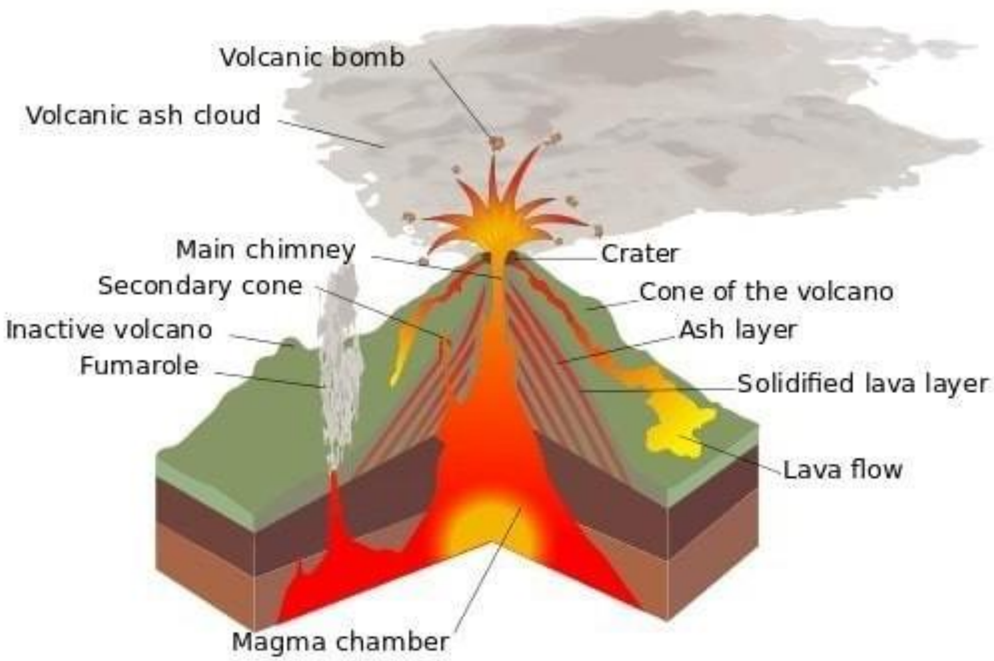
- Magma is composed of molten rock and is stored in the Earth's crust. Lava is magma that reaches the sur- face through a volcano vent.

Andesitic or Acidic or Composite or Strato-volcanic lava

- These lavas are **highly viscous** with a high melting point.
- They are **light-coloured, of low density, and have a high percentage of silica**.
- They **flow slowly and seldom travel far** before solidifying.
- The resultant volcanic cone is therefore stratified (hence the name **stratovolcano**) and steep-sided.
- The **rapid solidifying of lava** in the vent obstructs the flow of the out-pouring lava, resulting in **loud ex- plosions**, throwing out many volcanic **bombs or pyroclasts**.

- Sometimes the lavas are so viscous that they form a **lava plug** at the crater like that of **Mt. Pelée** in Marti- nique (an island in the Lesser Antilles, Caribbean Islands).
- Andesitic lava flow occurs mostly along the **destructive boundaries** (convergent boundaries).

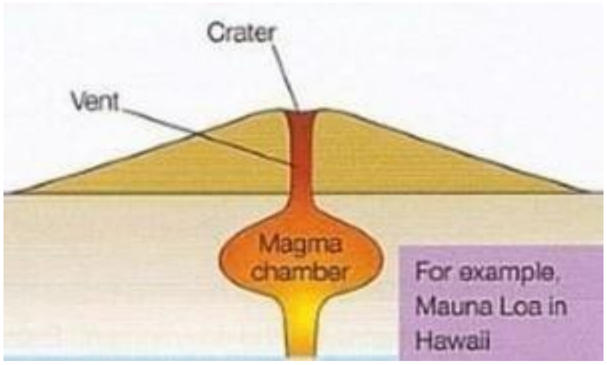
Lava Plug at the crater



Volcano (Medium69.Cette William Crochot, via Wikimedia Commons)

Basic or Basaltic or Shield lava

- These are the **hottest lavas**, about 1,000°Cand are **highly fluid**.
- They are **dark coloured 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.
- The resultant volcano is **gently sloping** with a wide diameter and forms a flattened shield or dome.
- Shield type lava flow is common along the **constructive boundaries** (divergent boundary).



Products of Volcanism

The volcano eruption consists of liquid, solid and gaseous materials. Let us learn about them:

(i) Solid: The solid material of different sizes is ejected out of volcano during eruptions. They are called as '**pyroclastic material**'. These materials of varying sizes and grades are known differently as follows:

- **Volcanic bombs**: Its size is generally >32 mm. They come out as liquid masses from volcanoes and are thrown in air and solidified. They have smooth surface and may be rounded or oblong in shape.
- **Lapilli or cinder**: They are also called as pumice stones. Their size ranges from 4 to 32 mm.
- **Volcanic Ash and volcanic dust**: They are fine grained and remain suspended in the atmosphere for a long time. They range in size between 0.25 and 4 mm.
- **Tuff**: Rocks made of ash and fine ash are known as tuff.
- **Agglomerate**: They are pyroclastic rocks consisting mainly of fragments larger than 20 mm in diameter.

(ii) Liquid: Magma is molten rock material consisting of mineral melt. It is most important product of volcanic eruption. On average the temperature of magma ranges between 1000° and 1200° C. The molten rock material below the surface is called '**magma**' and when it comes on the surface it is called **'Lava'.** Lava can be felsic (viscous) *or* mafic (less viscous or fluid).

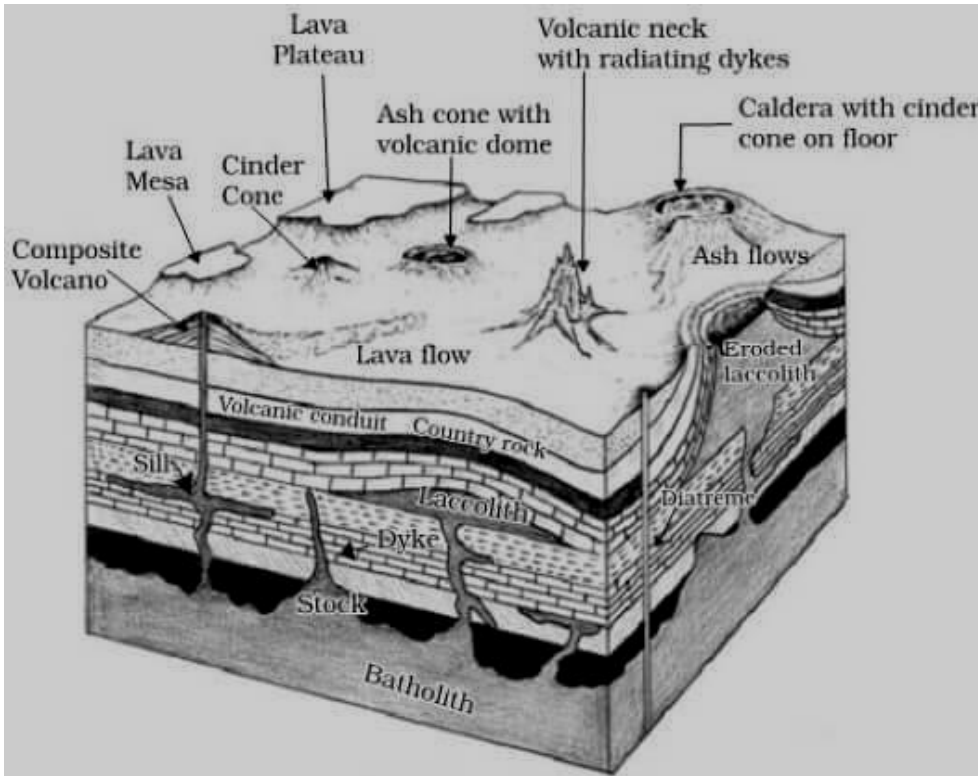
(iii) Gases: Water vapours form one of the most important part constituting 90% of the total volcanic gases. These water vapours may come from the original magma or due to boiling of underground water in the volcanic area. Other gases include NH_3, CO_2, N_2, SO_2, Cl_2, HCl, H_2S, Hydrocarbon gases and arsenic vapours.

There are certain features associated with the decaying phases of volcanism viz. **fumaroles, hot springs, geysers, geyserites, calcareous tuffa,** etc.

Volcanic Landforms

Volcanic landforms are controlled by the geological processes that form them and act on them after their formation. Volcanic landforms include both positive and negative relief features. The high or elevated relief features comprising of hills, mountains, cones, plateaus or upland plains are some of the examples of positive relief features. While the low lying features like craters, calderas, tectonic depression, etc. represent the negative relief features.

- Volcanic landforms are divided into **extrusive and intrusive landforms** based on whether 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 and Intrusive volcanic landforms

Extrusive Volcanic Landforms

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

Conical Vent and Fissure Vent

Fissure vent

- A fissure vent (volcanic 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 kilometres long.
- Fissure vents are common in **basaltic volcanism** (**shield type volcanoes**).

Conical vent

- A conical vent is a narrow cylindrical vent through which magma flows out violently.
- Conical vents are common in **andesitic volcanism** (**composite or stratovolcano**).

Mid-Ocean Ridges

- The system of mid-ocean ridges stretches for more than 70,000 km across all the ocean basins.
- The central portion of the mid-ocean ridges experiences frequent eruptions.
- The lava is **basaltic** (less silica and hence less viscous) and causes the **spreading of the seafloor**.

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 surface.
- **Andesitic lava** along with pyroclastic material accumulates in the vicinity of the vent openings leading to the formation of layers, and this makes the mounts appear as a **composite volcano or a stratovolcano** (divided into layers).

- The highest and most common volcanoes have composite cones.
- **Mount Stromboli (the Lighthouse of the Mediterranean)**, Mount Vesuvius, Mount Fuji are examples.

Shield Type Volcanic Landforms

- The **Hawaiian volcanoes** are the most familiar examples.
- These volcanoes are mostly made up of **basaltic lava** (very fluid).
- These volcanoes are not steep.

- They become explosive if somehow water gets into the vent; otherwise, they are less explosive.
- Example: Hawaiian volcanoes **Mauna Loa** (active shield volcano) and **Mauna Kea**(dormant shield volcano).

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: **Siberian Traps**, **Deccan Traps**, **Snake Basin, Icelandic Shield, Canadian Shield**.

Crater

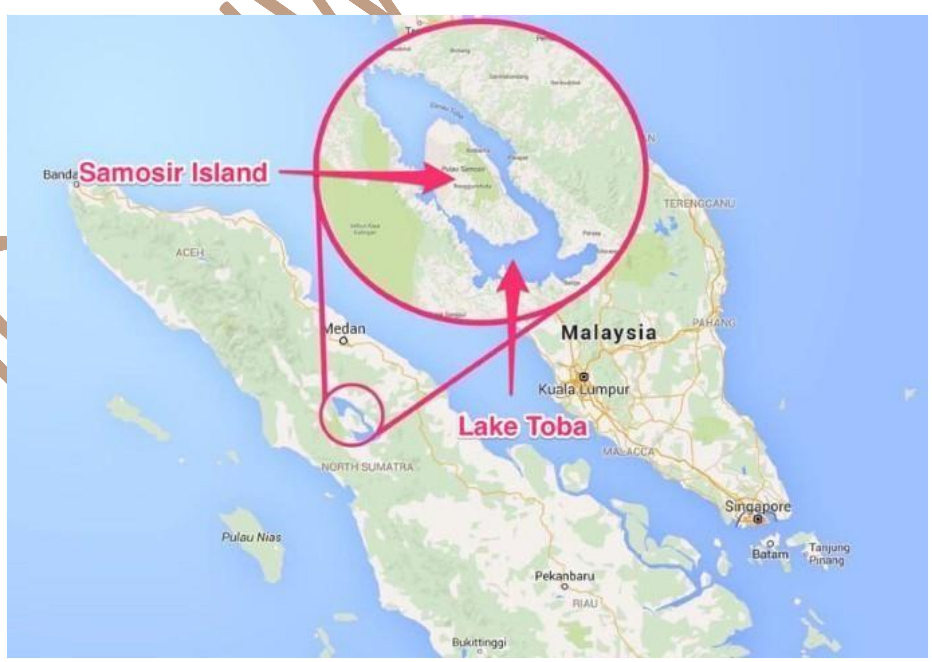
- A crater is an inverted cone-shaped vent through which the magma flows out. When the volcano is not ac- tive the crater appears as a bowl-shaped depression.

The crater of Mount Fuji, Japan

- When water from rain or melted snow gets accumulated in the crater, it becomes a **crater lake**.

Caldera

- In some volcanoes, the magma chamber below the surface may be emptied after volcanic eruptions.
- The volcanic material above the chamber **collapses** into the empty magma chamber, and the collapsed sur- face appears like a large cauldron-like hollow (tub shaped) called the caldera.
- When water from rain or melted snow gets accumulated in the caldera, it becomes a **caldera lake** (in gen- eral, the caldera lakes are also called crater lakes).
- Due to their unstable environments, some crater lakes exist only intermittently. Caldera lakes, in contrast, can be quite **large and long-lasting**.
- For example, **Lake Toba (Indonesia)** formed after its super volcanic eruption around 75,000 years ago. It is the **largest crater lake in the world**.



- Mount Mazama (Cascade Volcanic Arc, USA) collapsed into a caldera, which was filled with water to form Crater Lake (the literal name of the lake formed by the collapse of Mount Mazama is 'Crater Lake'!).

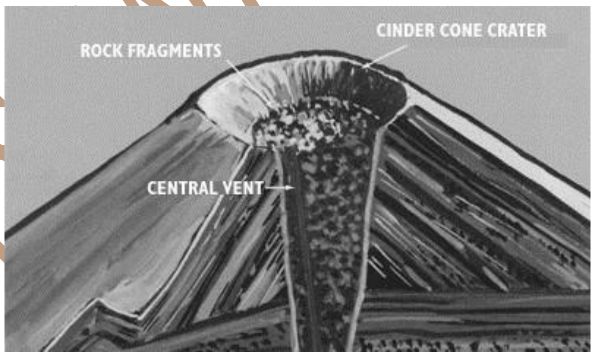
Caldera lake of Mount Mazama

A crater lake, in general, could be of volcanic origin (volcanic crater lake, volcanic caldera lake) or due to a meteorite impact (meteor crater or impact crater), or in the crater left by an artificial explosion caused by humans.

Lonar Lake, also known as Lonar crater (Lonar, Buldhana district, Maharashtra) was created by a meteor impact during the Pleistocene Epoch.

Cinder cone

- A cinder cone is a **steep circular or oval-shaped hill of loose pyroclastic fragments** that have been built around a volcanic vent.



Lava Dome

- A lava dome (volcanic dome) is a mound-shaped protrusion (a structure that extends outside the surface) resulting from the slow extrusion (coming out) of viscous lava from a volcano.
- In Lava domes, viscous **magma piles up** around the vent.
- The magma does not have enough gas or pressure to escape, although sometime later after sufficient pres- sure builds up, it may erupt explosively.

Lava dome protruding from a volcanic vent

Pseudo volcanic features

- Pseudo volcanic features are certain topographic features that resemble volcanic forms but are of non- volcanic origin. They include **meteorite crater, salt plugs, and mud-volcanoes**.

Meteorite Craters

- Meteorite craters are impact craters that are formed when a meteorite strikes the surface of the earth creat- ing a huge depression.

Salt plug or salt dome

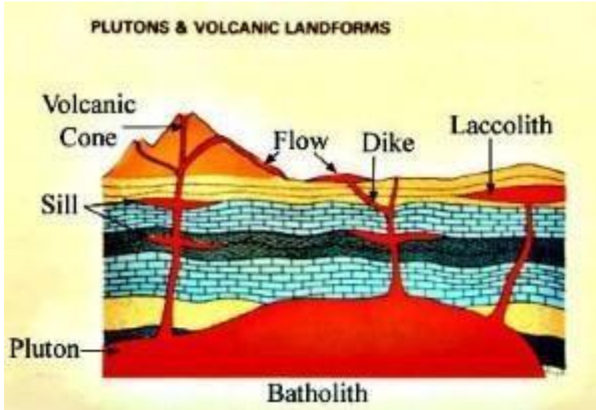
- A salt plug is formed when underground salt deposits at high pressure become ductile and pierce through the overlying sediments to create a diapir (a dome-like intrusion forced into brittle overlying rocks.
- Salt extrusions may take the form of salt hills which exhibit volcanic crater like features.
- Salt structures are impermeable and can lead to the formation of a **stratigraphic trap** (an impermeable lay- er capable of retaining hydrocarbons. **Structural traps**, in contrast, are cracks in faults and folds that can re- tain hydrocarbons).

Mud-volcanoes

- A mud volcano or mud dome is a landform created by the eruption of mud, water and gases.
- Mud-volcanoes have a similar shape to other types of volcanoes and contains several cones.
- They are usually found near the subduction zones and hot springs.
- Other mud volcanoes, entirely of a **non-volcanic origin**, occur near oil-fields where **methane and other volatile hydrocarbon gases** mixed with mud force their way upward.

Intrusive Volcanic Landforms

- Intrusive landforms are formed when magma cools within the crust.



Batholiths

- These are large **granitic** rock bodies formed due to 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 the surface after erosion.

Laccoliths

- These are large dome-shaped intrusive bodies connected by a pipe-like conduit from below.
- These are intrusive counterparts of an exposed domelike batholith.
- The **Karnataka plateau** is spotted with dome hills of granite rocks. Most of these, now exfoliated, are ex- amples 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 the top of the anticline in fold- ed igneous strata.
- Such wavy materials have a definite conduit to source beneath in the form of magma chambers (subse- quently developed as batholiths). These are called the Phacoliths.

Sills

- The near horizontal bodies of the intrusive igneous rocks are called sill. The thinner ones are called sheets.

Dykes

- When the lava makes its way through cracks and the fissures developed in the land, it solidifies almost **per- pendicular** 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**.

Volcanism Types

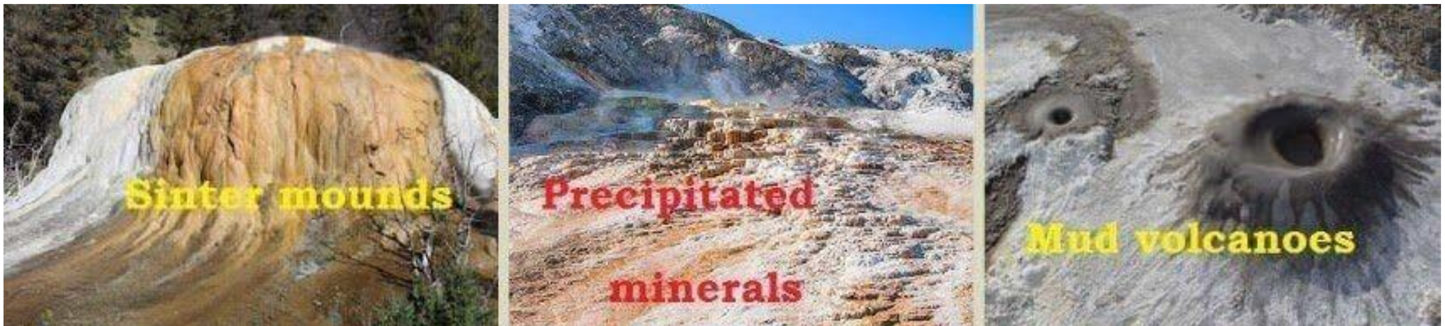
- Four types of volcanism can be identified.
  1. **Exhalative (vapour or fumes)**
  2. **Effusive (lava outpouring)**
  3. **Explosive (violent ejection solid material)**
  4. **Subaqueous Volcanism**

Exhalative (vapour or fumes)

This includes the discharge of material in **gaseous forms**, 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 sol- fataras.**
- This kind of volcanism indicates the volcano is reaching its **extinction**.
- Associatedlandformsarecalledsintermounds,conesofprecipitatedmineralsandmudvolcanoes.

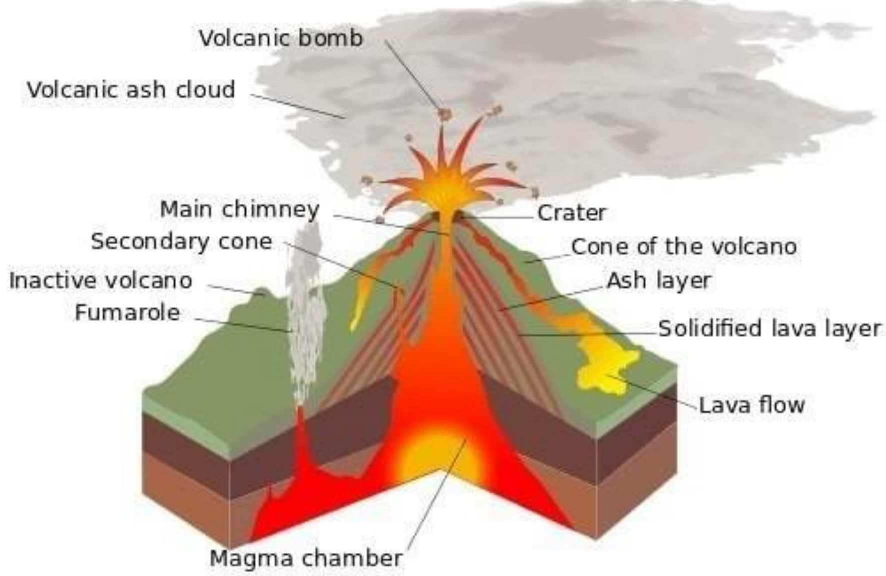


Effusive (Lava outpouring)

- Effusive: relating to or denoting igneous rocks poured out as lava and later solidified.
- This type of activity refers to **abundant outpourings of basaltic lava from a vent or fissure**.
- 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 (Deccan Traps near Mumbai).

Explosive (Violent ejection of solid material)

- This type of activity results in fragmentation and ejection of solid material through vents.
- Volcanic eject that settles out of air or water is sometimes called pyroclastic sediments.
- **Tephra:** all fragmented ejects from the volcanoes.
- **Ash:** The finest sand-sized tephra
- **Lapilli:** These are gravel-sized particles either in the molten or solid state.
- **Blocks:** Cobble or boulder-sized solid ejecta.
- **Bombs:** a lump of lava thrown out by a volcano.



- *Volcano (William Crochot, via Wikimedia Commons)*

- **Tuff:** Layers of volcanic dust and ashes.
- Smaller particles like lapilli and ash travel through air for many kilometres.
- The heavier particles like bombs and blocks fall in the vicinity of the vent.

Subaqueous Volcanism

- This type of volcanic activity takes places **below the surface of the water**.
- When lava is in contact with water, it consolidates to produce a structure like that of a heap of pillows
- Highly viscous lavas erupted at lesser depths develop glassy margins on pillows. The related volcanic prod- uct is **hyaloclastite**. Most hyaloclastites identified are in Iceland.

TYPES OF VOLCANOES

The most common type of volcanic eruption occurs when magma (the term for lava when it is below the Earth's surface) is released from a volcanic vent. Eruptions can be effusive, where lava flows like a thick, sticky liquid, or explosive, where fragmented lava explodes out of a vent. In explosive eruptions, the fragmented rock may be accompanied by ash and gases; in effusive eruptions, degassing is common but ash is usually not.

There is a wide range of variations in the volcanic eruption mode and their periodicity. Volcanologists classify eruptions into several different types. Some are named for particular volcanoes where the type of eruption is common; others concern the resulting shape of the eruptive products or the place where the eruptions occur. Thus, volcanoes are classified on the basis of (***a) the mode of eruption and (b) the period of eruption and the nature of their activities.***

1.5.1 CLASSIFICATION BASED ON THE NATURE OF VOLCANIC ERUPTIONS

During an episode of activity, a volcano commonly displays a distinctive pattern of behavior. Some mild eruptions merely discharge steam and other gases, whereas other eruptions quietly extrude quantities of lava. The most spectacular eruptions consist of violent explosions that blast great clouds of gas-laden debris into the atmosphere.

Most of volcanic eruptions takes place in two ways. They are: (i) Violent and Explosive type of eruption of lavas, volcanic dusts, ashes and fragmental materials through a narrow pipe and small openings under the impact of violent gases, and (ii) Fissure type of eruption along a long fracture or fissure or fault due to weak gases and huge volume of lavas. Thus, based on the nature and intensity of lava eruptions volcanoes are divided into two categories:

(1) Central eruption type

(2) Fissure eruption type

(1) **Central eruption type volcanoes:** Central or explosive type of eruptions are favored by high gas content and high viscosity magmas i.e. andesitic to rhyolitic magma. They occur thorough a central pipe and small openings by breaking and blowing off crustal surface due to violent and explosive gases accumulated inside the earth. The eruption is so rapid and violent that huge quantity of volcanic materials comprising of lava, volcanic dusts and ashes, fragmental materials etc., are ejected into the air up to thousands of meters. The explosive bursting of bubbles fragments the magma into clots of liquid that cool as they fall through the air. These solid particles become pyroclasts or volcanic ash. After dropping down from the air, all these particles or materials accumulate around the volcanic vent and form different kinds volcanic cones. The type of volcanic eruption is often labeled with the name of a well-known volcano where characteristic behavior is similar hence the use of such terms as "Strombolian," "Vulcanian," and others. Some volcanoes may exhibit only one characteristic type of eruption during an interval of activity others may display an entire sequence of types. Volcanoes of central eruption type may be subdivided into five major types as the following:

i. Hawaiian type of volcanoes:
ii. Strombolian type of volcanoes:
iii. Vulcanian type of volcanoes:
iv. Vesuvian type of volcanoes:
v. Pelean type of volcanoes:

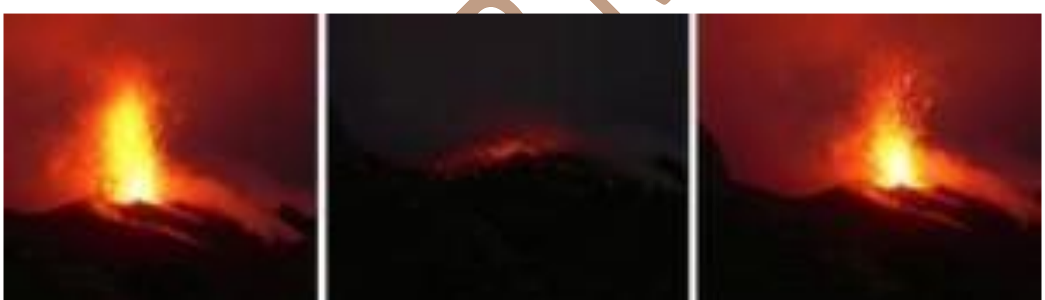
(i) Hawaiian Eruption

- Hawaiian eruptions are a type of volcanic eruption, named after the Hawaiian volcanoes.
- They are the **calmest types** characterised by the **effusive eruption** of very fluid **basalt-type lavas** from craters, lava lakes, fissures with **little-ejected material (low gaseous content)**.
- A single flow spreads widely over open slopes or flows down the valleys as Lava Rivers.
- Steady production of small amounts of lava builds up the large, broad form of a **shield volcano**.

- Eruptions **are not centralised** at the main summit as with other volcanic types and often occur at vents around the summit and from fissure vents radiating out of the centre.

(ii) Strombolian Eruption

- Strombolian eruptions are a type of volcanic eruption, named after Stromboli (Lipari Islands, Italy).
- Stromboli Volcano (**lighthouse of the Mediterranean**) has been erupting continuously for centuries.
- Strombolian eruptions are driven by the **continuous formation of large gas bubbles** within the magma.
- Upon reaching the surface, the bubbles burst with a loud pop, throwing magma in the air.
- Because of the high gas pressures associated with the magma, **episodic explosive eruptions** occur (erupts once in every few minutes – fountain like eruption).



Anak Krakatoa

- The greatest volcanic explosion known to humans is perhaps that of Krakatoa (**Plinian**) eruption in 1883.
- The explosion could be heard in Perth, Australia, almost 3,000 miles away.
- More than 36,000 people died, mostly from the tsunamis that followed the explosion.
- At present, Krakatoa (Krakatau or Krakatoa Archipelago) is a group of four small volcanic islands in the 2018 Sunda Strait tsunami
- The eruption of Anak Krakatoa in December 2018 and subsequent collapse of the southwest sector of the volcano, including the summit, triggered the tsunami that has killed more than 400 people.
- While Indonesia possessed a tsunami warning system for tsunamis caused by earthquakes, there were none in place for volcanic tsunamis, and hence there were no early warnings.

(iii) Vulcanian Eruption

- In Vulcanian eruptions, intermediate viscous magma within the volcano makes it difficult for gases to es- cape.
- This leads to the **build-up of high gas pressure**, eventually resulting in an **explosive eruption**.

- They are also more explosive than their Strombolian counterparts, with eruptive columns often reaching between 5 and 10 km high.
- The molten lava is explosively ejected as a great cauliflower cloud of dark tephra. Bombs, blocks, lapilli and other ejecta fall in the surrounding area.
- After each eruption cycle, **the volcano is dormant for decades or centuries**.

(iv) Plinian Eruption

- Plinian eruptions (form of Vesuvian **eruption**) are a type of volcanic eruption, named after the historical eruption of **Mount Vesuvius** in 79 AD that buried the Roman town of Pompeii.
- In Plinian eruptions, dissolved volatile gases stored in the magma are channelled to the top through a nar- row conduit (pipe-like structure).
- The gases erupt into a **massive column** of the gas plume that reaches up **2 to 45 km into the atmos- phere**.
- As it reaches higher the plume expands and becomes less dense and convection and thermal expansion of volcanic ash drive it even further up into the stratosphere.
- At the top of the plume, powerful prevailing winds drive the plume in a direction away from the volcano.

Mount Vesuvius

- Mount Vesuvius is a stratovolcano in Bay of Naples, Italy.

- It is best known for its **Plinian type** eruption in AD 79 that led to the destruction of the Roman cities of Pompeii, Herculaneum and others. More than 1,000 people died in the eruption.
- The eruption ejected a cloud of stones, ashes and volcanic gases to a height of more than 30 km.
- Vesuvius has erupted many times since. Today, it is regarded as **one of the most dangerous volcanoes** in the world because of the population of 3,000,000 people living nearby.
- The eruptions alternated between Plinian and Peléan with most of them being Plinian type.

(v) Pelean Eruption

- Peléan eruptions are a type of volcanic eruption, named after the volcano **Mount Pelée in Martinique**.
- In Peléan eruptions, a large amount of gas, dust, ash, and lava fragments are blown out **laterally** by the **collapse of the cinder cone**. The sudden burst of lava dome causes the collapse of the cinder cone.
- This type of eruption results in very viscous, gas-rich, acidic lava **breaking out laterally and flowing out violently** at high speed causing massive destruction on its path.
- Hot gas and lava mixture are not carried skyward to become cold tephra but spreads down slope as a **nuceardente**, continuing to **cushion** the flowing fragments.

Pelean Eruption

Mount Pelée

- Mount Pelée is a volcano at the northern end of Martinique Island (French overseas department in the Lesser Antilles island arc of the Caribbean).
- The volcano is famous for its Pelean type eruption in 1902 that killed about 30,000 people.
- Most deaths were caused by pyroclastic flows which destroyed the city of Saint-Pierre.

Volcanic Explosivity Index

The Volcanic Explosivity Index (VEI) was devised by Chris Newhall of United States Geological Survey and Stephers Self at University of Hawaii. VEI is a scale, from 0 to 8, for measuring the strength of volcanic eruptions. It operates in a way like the Richter Scale for earthquakes, in that each interval in value represents a tenfold increasing in magnitude. It is a relative study to measure explosivity of volcano.

VEI	Description	Plume Height	Volume	Classification	How often
0	non-explosive	-100 m	1000s m3	Hawaiian	daily
1	gentle	100-1000 m	10,000s m3	Haw/Strombolian	daily
2	explosive	1-5 km	1,000,000s m3	Strom/Vulcanian	weekly
3	severe	3-15 km	10,000,000s m3	Vulcanian	yearly
4	cataclysmic	10-25 km	100,000,000s m3	Vulc/Plinian	10's of years
5	paroxysmal	+25 km	1 km3	Plinian	100's of years
6	colossal	+25 km	10s km3	Plin/Ultra-Plinian	100's of years
7	super-colossal	+25 km	100s km3	Ultra-Plinian	1000's of years
8	mega-colossal	+25 km	1,000s km3	Ultra-Plinian	10,000's of years

(2) Fissure eruption type volcanoes

These types of volcanoes occur along a long fracture, fault and fissure and there is slow upwelling of magma from below and the resultant lavas spread over the ground surface. The lave speed depends on the nature of magma, volume of magma, slope of ground surface and temperature conditions. Thus, the fissure eruption type of volcanoes is of three kinds. They are:

(a) Lava flood or lava flow

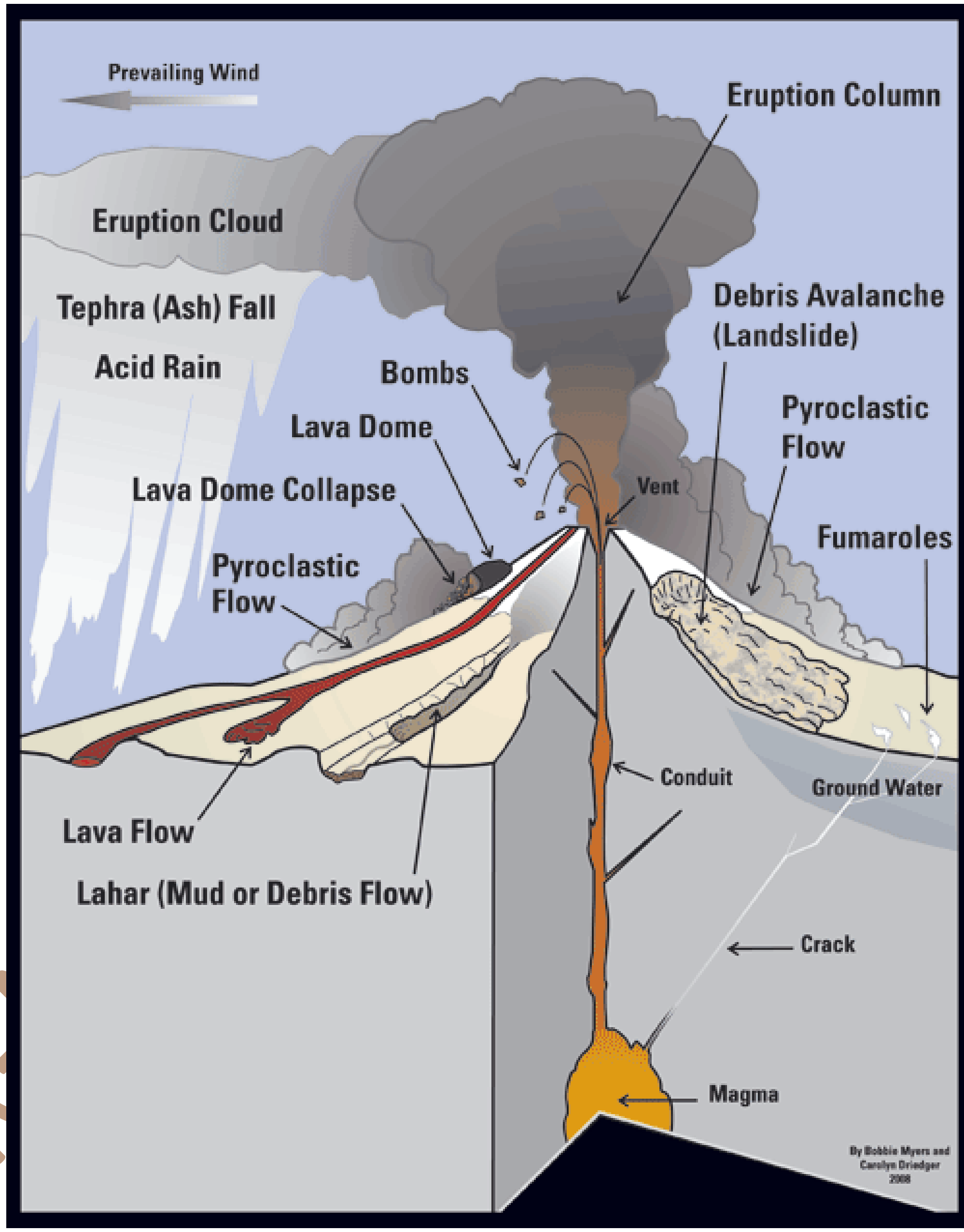
(b) Mud flow and

(c) Fumaroles

(a) Lava Flood: Lava floods, also known as lava flows, are common in Hawaiian and Strombolian type of eruptions, the least explosive. Although they have been known to travel as fast as 64 km/hr, most are slower and give people time to move out of the way. Thus, in general, lava flows are most damaging to property, as they can destroy anything in their path.

(b) Mud flow: A volcanic eruption usually leaves lots of loose unconsolidated fragmental debris. When rapid melting of snow and ice by pyroclasitic flows, intense rainfall on loose volcanic rock deposits, breakout of a lake or draining of a crater lake, and as consequence of debris avalanches, a mudflows result.

Rapidly flowing mixture of rock debris and water that originate on the slope of a volcano is called as mud flow. Volcanic mudflows are called ***lahars***. These can occur accompanying an eruption or occur long after an eruption. Lahars may be hot or cold and move at high velocity as they fill stream valleys that drain the volcano. At the base of the volcano, they spread out and cover wide areas. In general, they dev estate anything in their path, carrying away homes, buildings, bridges, and destroying roads, and killing livestock and people. It is important to understand that lahars can occur accompanying an eruption, or can occur simply as the result of heavy rainfall or sudden snow melt, without an eruption.



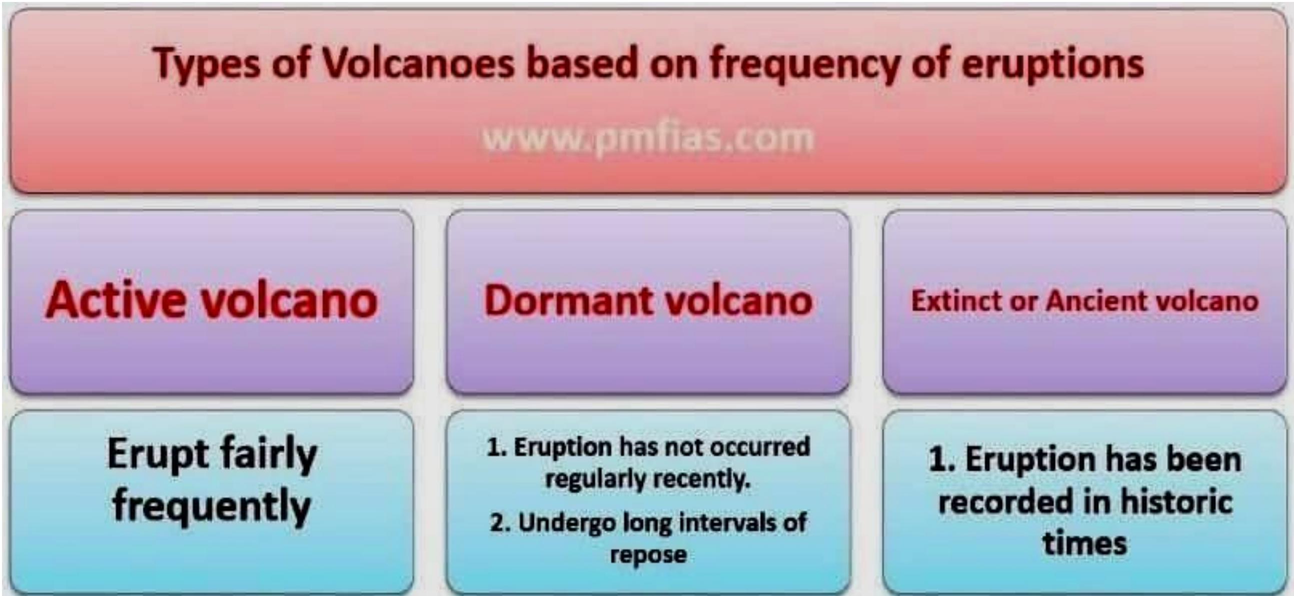
(c) Fumaroles: Fumaroles are vents from which emits steam and volcanic gases into the atmosphere. Fumaroles can occur along tiny cracks or long fissures, in chaotic clusters or fields, near active volcanoes or in the areas where magma has been risen into the earth's crust without erupting on the surface. They may persist for decades or centuries if they are above a persistent heat source (active Magma chamber) or disappear within weeks to months if they occur atop a fresh volcanic deposit that quickly cools. The temperatures rise from 70 C - 100 C or more. In some cases, they are hidden in the ground (like in Stephanos-Crater on Nisyros) and you can break into them. The gases are dangerous and a gas-mask is often needed. They are always a sign of active volcanism.

https://youtu.be/8KN0uXEOhWU

1.5.2 TYPES OF VOLCANOES ON THE BASIS OF PERIODICITY:

On the basis of period of eruption and time interval between two eruptions, volcanoes can be divided into three types. They are:

(i) Active volcanoes
(ii) Dormant volcanoes and
(iii) Extinct volcanoes



(i) **ACTIVE VOLCANOES**:

The volcanoes from whose vents there is constant eject of volcanic materials such as, lava, ashes, gases and fragmental materials etc. are known as active volcanoes. In view of volcanologists, an active volcano is a volcano which has shown eruption activity within recorded history. Some of the active volcanoes are continually in eruption, while in other cases the eruptions are intermittent. According to **Worcester**, at present, there are about 500 active volcanoes in the world and most of them being in the Pacific Ocean, and in the atlantic Isalnds. Besides, there are other active submarine volcanoes whose number it is difficult to determine. A few examples of active volcanoes are: Anak Krakatoa (Indonesia), Etna (Sicily), Vesuvius (Italy), Mount Pelee (Martinique), Mount Karmai (Alaska), Mount Saint Helens, Nevado Del Ru'z (Columbia), Mount Unzen (Japan), Mount Pinatubo (Philippines), Mount Redoubt (Alaska), Mount Mayon (Philippines) and Barren island (A & N islands, India) etc. The Stromboli volcano which emits continuous fire and incandescent gases that it is known as 'the Light House of the Mediterranean Sea'. Besides active volcanoes are found in Alaska, Aleutian Islands, Kamchatka, the Kurile Islands, Japan, Taiwan, Philippines and the Moluccas group.

(ii) DORMANT VOLCANOES:

The volcanoes which remain quiet after their eruptions for some time, or which do not show any sign of volcanic activity for a long time, but there is a possibility of eruption in future are known as dormant volcanoes. It means they are in a state of inactivity. According to volcanologists, a dormant volcano is a volcano which has not shown eruptive activity within recorded history, but shows the signs of eruptive activity within the recent geologic past. In other words, a dormant volcano is somewhere between active and extinct state. But all of a sudden there will be an explosive eruption with the result that there would be unimaginable loss of life and property. It should be noted that whenever a dormant volcano develops as an active one, the eruption is apt to be extremely violent, for during the period of quiet type, the lava in the channel has solidified and given rise to an obstacle which only a great and violent explosion can remove. It is worth mentioning that violent eruptions of such dormant volcanoes are generally preceded and accompanied by earthquakes, some of which have been very destructive. Mount Kilimanjaro (strato-volcano) in Tanzania and mount Fuzi in Japan are fine examples of dormant volcanoes.

(iii) EXTINCT VALCONES:

When the eruption of a volcano is completely ceased with no indications of future eruption or volcanic activity, such kind of volcano is known as extinct volcano. In other words, it a volcano that has not shown any historic activity, is usually deeply eroded, and does not show signs of recent activity. How old must a volcano be to be considered extinct depends to a large degree on past activity. In extinct type, the crater is covered with water and crater lakes are formed. Although we must remember that many of these are considered dormant may become active any day as no one knows what is happening below the ground surface. A few examples of extinct volcanoes are Kyushu-Palau Ridge in the Philippine Sea, Huascarán in Peru, Mount Buninyong in Australia, and Narkondam Island in A & N islands, India.

It may be pointed out that it is rather difficult to classify definitely a volcano as active, dormant or extinct. Some of the volcanoes that are today dormant may become active. Monte Somma was considered an extinct volcano by the inhabitants of Pompeii and Herculaneum in 79 A.D. because it had been inactive for 700 years, yet in that year (79 A.D.) there was a disastrous eruption.

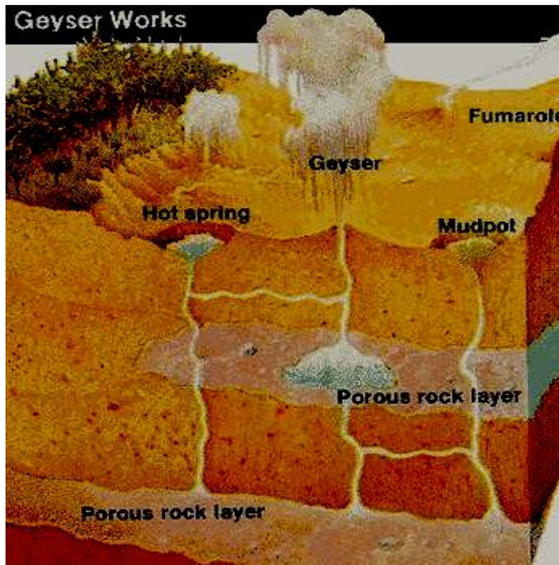
How a volcano becomes extinct or inactive is associated with the movement of plates. As we know, a volcano can form over the hot spot, but because the plate is moving, the volcano is carried away from its source of magma after a few million years and becomes inactive. It is replaced at the hot spot by a new volcano a short distance away. A chain of volcanoes and volcanic islands results. 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.

1.6 GEYSERS AND HOT SPRINGS

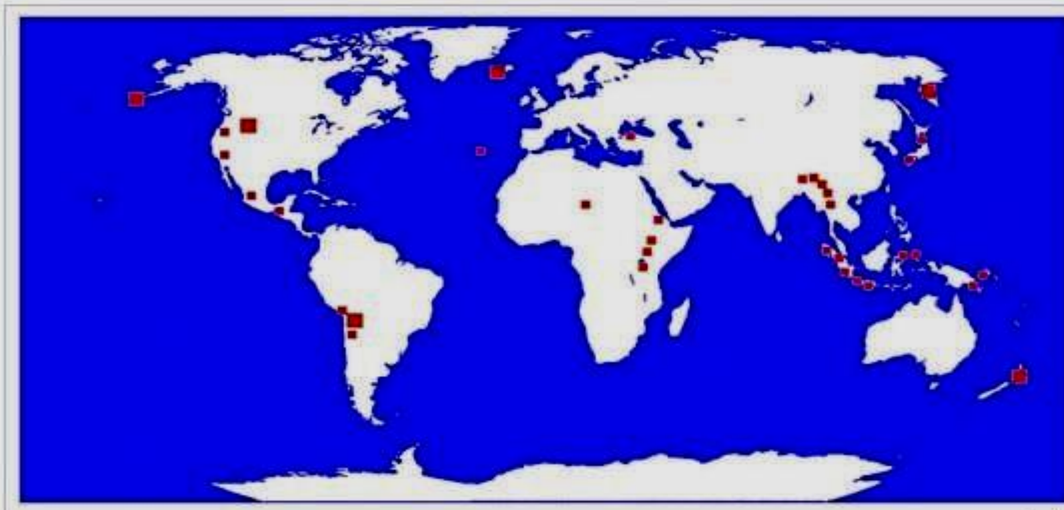
- Water that percolated into the porous rock is subjected to intense heat by the underlying hard rock which is in contact with hot magma in the mantle or the lower part of the crust.
- Under the influence of intense heat, the water in the capillaries and narrow roots in the porous rock under- goes intense 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 frac- tures. 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 aspring.
Silicate deposits at mouth give them their distinct colours.	Some springs are very colourful because of the pres- ence of **cyanobacteria** of different colours.
Generally, geysers are located near active volcanic areas. **Iceland** is famous for its geysers.	Found all across the world
Usually, a carter like structure is created at the mouth.	



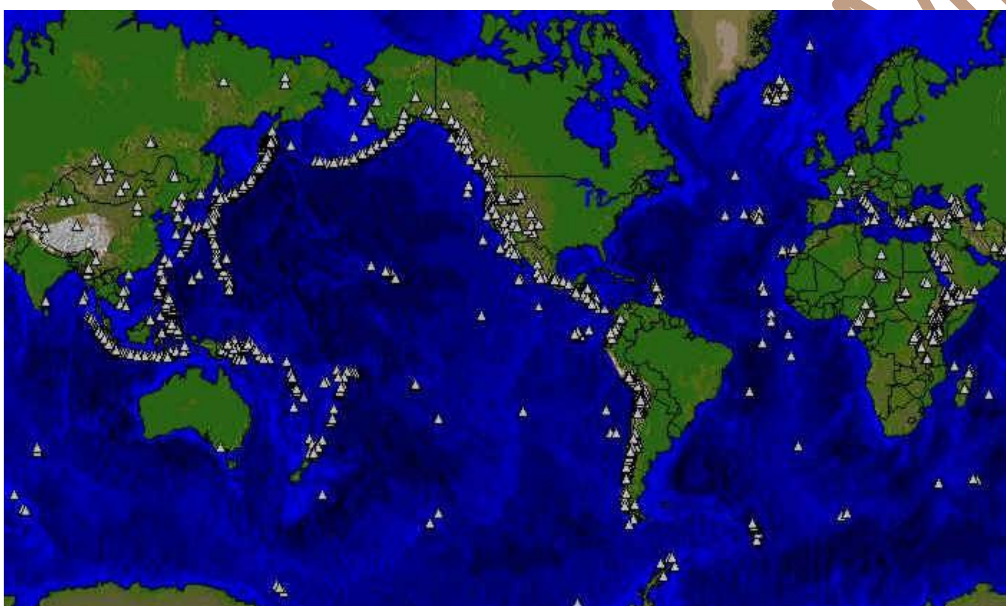
- Almost all the world's geysers are confined to three major areas: **Iceland, New Zealand and Yellowstone Park of U.S.A**.

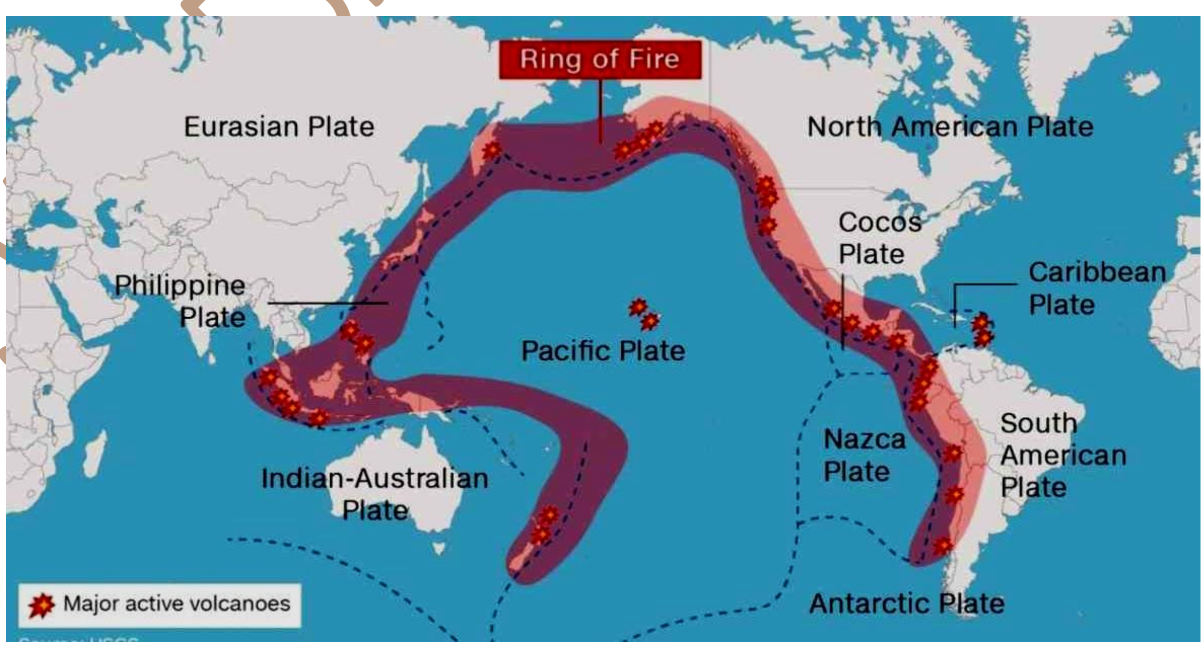


Distribution of major geysers in the world.

1.7 DISTRIBUTION OF VOLCANOES ACROSS THE WORLD

- Most known volcanic activity and the earthquakes occur along converging plate margins and mid- oceanic ridges.
- Around 80% of volcanic activity is found along subduction boundaries. Mid-ocean spreading centres and continental rifts account for around 15% of volcanic activity. Rest is intra-plate volcanism.
- 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.





i. Pacific Ring of Fire

- Circum-Pacific region popularly termed the **'Pacific Ring of Fire'**, also known as 'Fire Girdle of the Pacific', has the greatest concentration of active volcanoes. Volcanic belt and earthquake belt closely overlap along the 'Pacific Ring of Fire'.

Regions with active volcanism along 'Pacific Ring of Fire':

- The 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.

The 5 countries with the most volcanoes:

1. United States – 173 (most of them are in Alaska)
2. Russia - 166
3. Indonesia - 139
4. Iceland - 130
5. Japan – 112

ii. Mid-Continental Belt

- This belt is also known as 'the volcanic zones of convergent continental plate mergins'.
- A few basaltic volcanoes of fissure eruption type also occur along the mid-oceanic ridge, where seafloor spreading is in progress.
- This belt comprises of the volcanoes of Alpine mountain chains, Mediterranean Sea and the volcanoes of fault zone of eastern Africa.
- Here volcanoes are caused due to collision of African, Eurasian and Indian plates.
- The famous volcanoes of Mediterranean Sea i.e. Vesuvius**,** Strom- boli (Light House of the Mediterranean) and those of the Aegean islands are come in this belt. The important volcanoes of fault zone of eastern Africa or **East African Rift Valley are** Mt. Kilimanjaro, Mt. Elgn, Mt meru **and** Mt. Kenya etc.

iii. Mid-Atlantic Belt

- A few basaltic volcanoes of fissure eruption type also occur along the mid-oceanic ridge, where seafloor spreading is in progress in Atlantic Ocean.
- These volcanoes are mainly of fissure eruption type.
- They mostly occur along the divergent plate boundaries or margins.
- The important volcanic areas include the volcanoes of west indies, lesser Antilles, southern Antilles, Azores and St. Helena islands etc.

iv. Intra-Plate Volcanoes

- Besides the above three zones of volcanoes, there are other volcanoes which are scattered and found in the inner parts of the continents.
- Such distribution of volcanoes is called as intra-plate volcanoes.
- They occur in the middle of plate boundaries where magma exits from weaknesses in the earth's surface.

- The Hawaiian Islands are an example of hot spot volcanoes.

Mediterranean volcanism

- Volcanoes of the Mediterranean region are mainly associated with the Alpine folds, e.g. **Vesuvius**, **Strom- boli (Light House of the Mediterranean)** and those of the Aegean islands.
- A few continue into Asia Minor (Mt. Ararat, Mt. Elbruz).
- The volcanism of this broad region 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 the Mediterranean plate** into multiple plates due to the interaction of African and Eurasian plate

Volcanos in India

- There are **no volcanoes in the Himalayan region** or the Indian peninsula.
- **Barren Island (only active volcano in India)** in the Andaman and Nicobar Islands became active in the 1990s.
- It is now considered an [active volcano] after it spewed lava and ash in 2017.
- 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 destroyed.

1.8 Effects of Volcanoes

The main types of volcanic hazards can be studied into two ways. They are:

1. Destructive effects of volcanoes
2. Positive effects of volcanoes

(1) Destructive effects of volcanoes

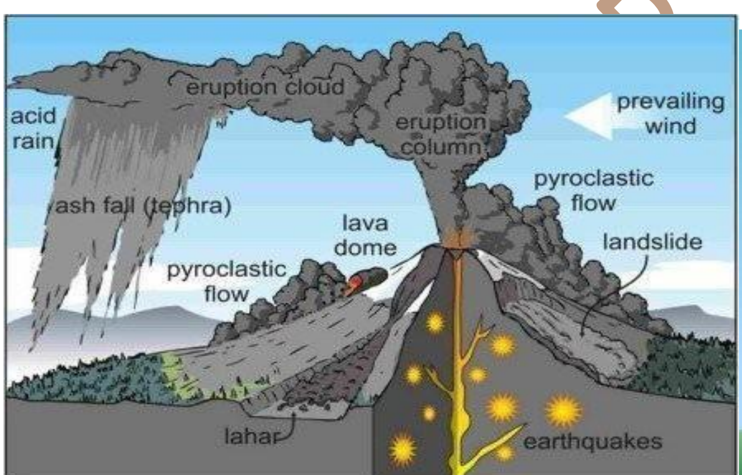
- Showers of cinders and bombs can cause damage to life. E.g. the eruption of **Mount Vesuvius** in 79 AD.
- Tsunamis can be generated in large water bodies due to violent eruptions. E.g. 1883 Krakatoa eruption.
- The collapse of the volcanic landforms in seas and oceans cause tsunamis. E.g. 2018 Sunda Strait tsunami.
- The ash from a larger eruption dispersing over a large area can lower temperatures at a regional or global scale. This could trigger

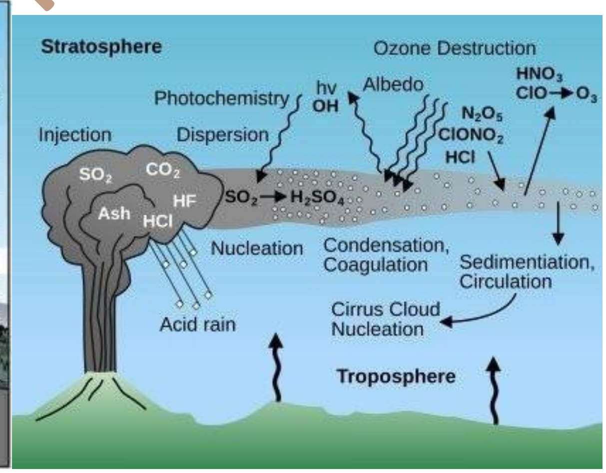
famines on a large scale. E.g. 1815 eruption of Mount Tambora.

- In Hawaiian type eruption, a single flow spreads widely over open slopes or down the valleys as lava rivers engulfing entire cities.
- Lahars (a violent type of mudflow or debris flow) can bury entire cities in a matter of minutes causing a high number of causalities. E.g. 1985 eruption of Nevado del Ruiz volcano.
- The sudden collapse of lava domes can cause violent volcanic flows that destroy everything on their path. E.g. the 1902 eruption of Mount Pelée.
- Powerful winds drive the gas plume higher into the atmosphere and carry it to a greater distance disrupting air travel (this happened in 2010 when a stratovolcano in Iceland erupted and disrupted air travel over en- tire Europe for weeks).
- A supervolcanic super-eruption can cause a small-scale extinction event. E.g. The Toba eruption (Indonesia) triggered a dramatic global winter 74,000 years ago.

Volcanism – Acid Rain, Ozone Destruction

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





(2) Positive Effects of Volcanoes

- Volcanism creates new fertile landforms like islands, plateaus, volcanic mountains etc. E.g. Deccan traps.
- 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, the source of diamonds, is the pipe of an ancient volcano.

- In the vicinity of active volcanoes, waters in 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, centred around volcanoes. E.g. Yellowstone National Park.
- As a source of crushed rock for concrete aggregate or railroad ballast and other engineering purposes, lava rock is often extensively used.

MODULE -06 ROCKS: DEFINATION, TYPES AND DISTRIBUTION

Living on the solid surface of the earth we are very aware of the materials that surround us and the processes that modify them. The materials are substances such as rocks, sand, clay and organic matter etc. the processes change the materials and move them around. The materials of the earth's crust or lithosphere are generally called as rocks. The word lithosphere, in fact, means "rock sphere" as the literal meaning of 'lithos' is rock. Rock is any naturally formed, non-living, firm, and coherent aggregate mass of solid matter that constitutes part of a planet.

A rock can be defined as a solid substance that occurs naturally since of the effects of three basic geological processes, namely- magma solidification, sedimentation of weather rock debris, and metamorphism. The smallest component of the earth's crust or the lithosphere is element. Most rocks are composed of various minerals. Several geologists defined minerals as "naturally occurring inorganic solids which have structure of crystalline and a distinct chemical composition. The minerals that occur in the rocks of earth's crust are produced through a variety of differing arrangements of chemical elements (table 6.1). Over two thousands minerals have been identified by earth scientists. As regards the whole earth eight most abundant elements- iron, oxygen, silicon, magnesium, nickel, sulphur, calcium and ammonium) constitute 99 percent of the total mass of the earth whereas only four elements – oxygen, silicon, iron and magnesium, account for 90 percent of total mass of the earth.

Table 6.1: Common elements found in the rocks of Earth's Crust.

Element	Chemical Symbol	Percent Weight in Earth's Crust
Oxygen	O	46.60
Silicon	Si	27.72
Aluminum	Al	8.13
Iron	Fe	5.00
Calcium	Ca	3.63
Sodium	Na	2.83
Potassium	K	2.59
Magnesium	Mg	2.09

- Rock is an aggregate of one or more minerals held together by chemical bonds.
- Feldspar and quartz are the most common minerals found in rocks.
- The scientific study of rocks is called petrology.

  The crustal rocks have been classified on several grounds e.g. mode of formation, physical and chemical properties, locations etc.
- Based on the mode of formation, the rocks are classified into three major groups: igneous, sedimentary, and metamorphic.

  (i) **Igneous Rocks** — solidified from magma and lava.
  (ii) **Sedimentary Rocks** — the result of deposition of fragments of rocks.
  (iii) **Metamorphic Rocks** — formed out of existing rocks undergoing recrystallisation.

(i) IGNEOUS ROCKS

- The word igneous has been derived from a Latin word 'ignis', meaning there by fire. It does not mean that the origin of igneous rocks is associated with fire in any way.
- In fact, the cooling, solidification and crystalization of magma formed the first rocks on earth.
- Rocks formed out of solidification of magma (molten rock below the surface) and lava (molten rock above the surface) and are known as igneous or primary rocks.
- Having their origin under conditions of high temperatures the igneous rocks are unfossiliferous.
- Granite, gabbro, basalt, are some of the examples of igneous rocks.
- There are three types of igneous rocks based on place and time taken in cooling of the molten matter, plutonic rocks, volcanic rocks and intermediate rocks.
- There are two types of rocks based on the presence of acid-forming radical, silicon, acidic rocks and basic rocks.

The igneous rocks are more commonly classified on the basis of the mode of occurrence into two major groups: intrusive igneous rocks and extrusive igneous rocks.

1. Intrusive igneous rocks:

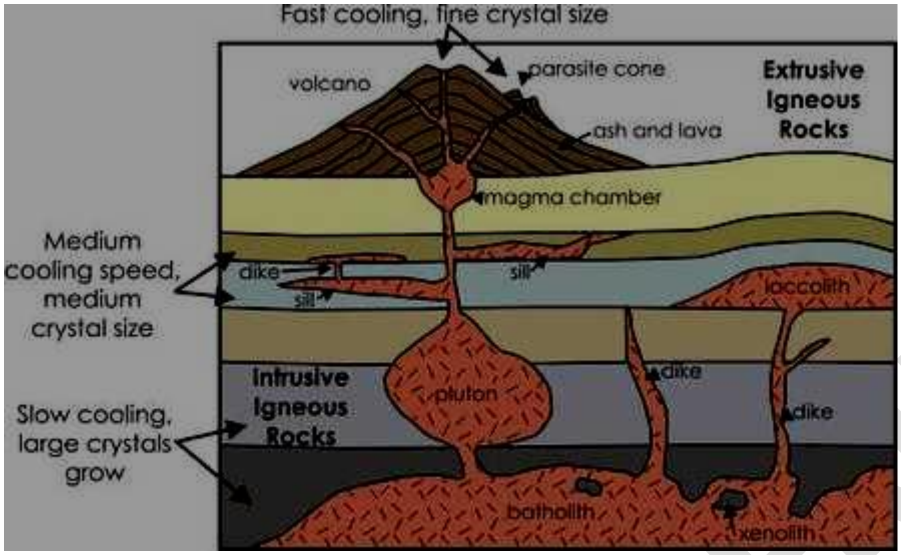
When magma never reaches the surface and cools to form intrusions (dykes, sills etc) the resulting rocks are called intrusive igneous. Depending on their silica content, they are called (in ascending order of silica content) gabbro, diorite, granite and pegmatite. By quantity, these are the by far most common rock types. Most magma actually never reaches the surface of the earth. On the basis of the depth of magma cooling place from the surface of the earth, these are of two sub-types, namely Plutonic and Hypabyssal Igneous rocks.

a) Plutonic Igneous rocks:

- These are formed due to cooling of magma very deep inside the earth.
- If magma cools slowly at great depths, mineral grains formed in the rocks may be very large.
- Such rocks are called intrusive rocks or plutonic rocks (e.g. Granite).
- These rocks appear on the surface only after being uplifted and denuded.

b) 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.



i. Batholiths
ii. Laccoliths
iii. Lapoliths
iv. Sills
v. dykes

2. Extrusive igneous rocks (Lava or Volcanic rocks

Igneous rocks are called **extrusive** when they cool and solidify above the surface. These rocks usually form from a volcano, so they are also called **volcanic rocks**.

- Suddencoolingofmagmajustbelowthesurfaceorlavaabovethesurfaceresultsinsmallandsmoothgrains in rocks as rapid cooling prevents crystallisation, as a result, such rocks are fine-grained.

- Such rocks are called extrusive rocks or volcanic rocks (e.g. Basalt).
- The Deccan traps in the Indian 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.

On the basis of amount of silica (S_iO_2) igneous rocks are of two groups:

Acid Rocks

- Acidic rocks are characterised by high content of silica (quartz and feldspar)—up to 80 per cent.
- The rest is divided among aluminium, alkalis, magnesium, iron oxide, lime etc.
- These rocks have a lesser content of heavier minerals like iron and magnesium. Hence, they are less dense and are lighter in colour than basic rocks.
- 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.
- Add rocks are hard, compact, massive and resistant to weathering.
- Granite, quartz and feldspar are typical examples.

Basic Rocks

- These rocks are poor in silica (about 40 per cent); magnesia content is up to 40 per cent, and the remaining 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 give rise to plateaus.
- Presence of heavy elements imparts to these rocks a dark colour. Not being very hard, these rocks are weathered relatively easily.
- Basalt, gabbro and dolerite are typical examples.

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 materials as they come in beautiful shades.

(ii) SEDIMENTARY ROCKS

Sedimentary rocks are formed by lithification—consolidation and compaction of sediments. The word 'sedimentary' has been derived from Latin word 'sedimentation' which means 'setting down'. Sedimentary rocks are also called as stratified or layered rocks.

Sedimentary rocks are formed on the earth's surface under normal surface temperature and pressures. They result from the accumulation of the products of weathering of other rocks and organic materials. Weathering is a general term used for the physical and chemical breakdown of rocks at the earth's surface by rain, wind, abrasion etc. Products of weathering are either transported or may accumulate where they are formed. The processes of transforming loose fragmented rocks into a compact solid cohesive mass is called lithification. This process is also known as consolidation, and the resultant rock is said to be consolidated. Sandstone is a consolidated rock, while sand is an example of an unconsolidated rock.

- Hence, they are layered or stratified of varying thickness. Example: sandstone, shale etc.
- Sediments are a result of denudation (weathering and erosion) of all types of rocks.
- These types of rocks cover 75 per cent of the earth's crust but volumetrically occupy only 5 per cent (because they are available only in the upper part of the crust).
- Ice deposited sedimentary rocks are calledtill or tillite. Wind-deposited sediments are called loess.

Sedimentary rocks can be divided into four main types: clastic, chemical, biochemical, and organic. Clastic sedimentary rocks are composed mainly of material that is transported as solid fragments (called clasts), and then cemented together by minerals that precipitated from solution. Chemical sedimentary rocks are composed mainly of material that is transported as ions in solution. Biochemical sedimentary rocks also form from ions in solution, but organisms play an important role in converting those ions into calcium carbonate or silica body parts. Organic sedimentary rocks contain large amounts of organic matter, such as from plant leaves and tree bark.

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

1. *mechanically formed — sandstone, conglomerate, limestone, shale, loess.*
2. *organically formed — geyserite, chalk, limestone, coal.*
3. *chemically formed—limestone, halite, potash.*

Mechanically Formed Sedimentary Rocks

Lithification (Figure 6.3) is the process of converting sediments into solid rock. Compaction is the first step. Sediments that have been deposited are buried when more and more sediments accumulate above them. The weight of the overlying sediments pushes the clasts together, closing up some of the pore spaces (the gaps between grains) and forcing them together. Pore spaces often contain water (although they can also contain air or even hydrocarbons), so the water is squeezed out.

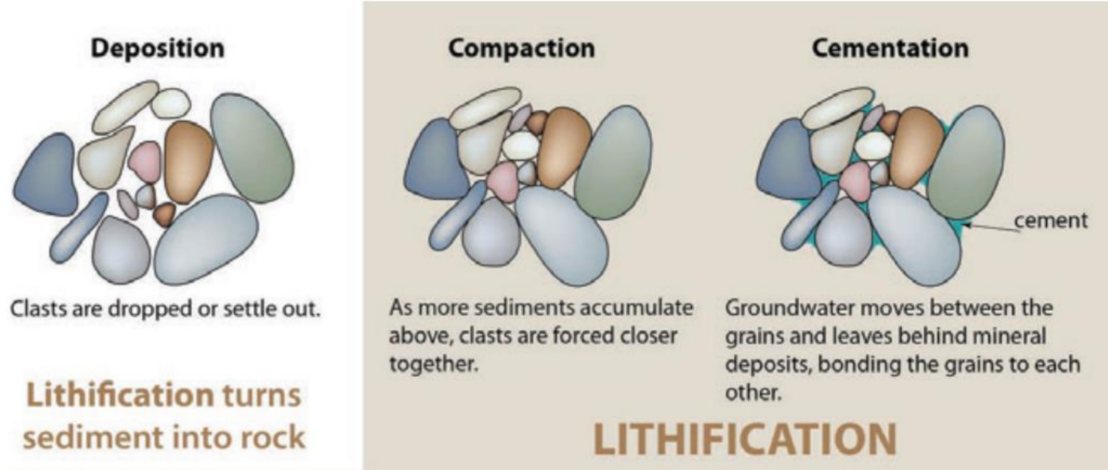


Figure 6.3: lithification of sedimentary rocks

Cementation is the next step. Groundwater flowing through the remaining pore spaces contains ions, and these ions may precipitate, leaving behind minerals in the pore spaces. These minerals bind the grains together, and are referred to collectively as cement. Quartz and calcite are common cement minerals, but depending on pressure, temperature, and chemical conditions, cement might also include other minerals such as hematite and clay.

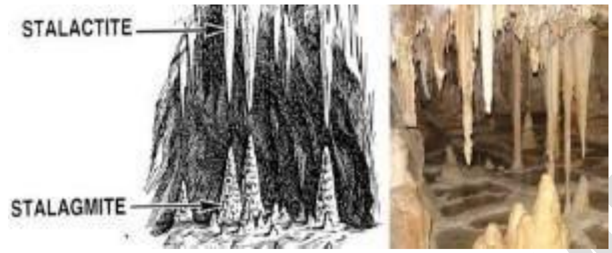
- They are formed by mechanical agents like running water, wind, ocean currents, ice, etc.
- Arenaceous sedimentary rocks have more sand and bigger sized particles and are hard and porous. They form the best reservoirs for liquids like groundwater and petroleum. E.g. sandstone.
- Argillaceous rocks have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

Chemically Formed Sedimentary Rocks

Clastic sedimentary rocks are dominated by components that have been transported as solid clasts (clay, silt, sand, etc.). In contrast, chemical and biochemical sedimentary rocks are dominated by components that have been transported as ions in solution (e.g., Na^+ , Ca^{2+}, HCO_3^- , etc.). There is some overlap between the two because almost all clastic sedimentary rocks contain cement formed from dissolved ions, and many chemical sedimentary rocks include some clasts. The difference between chemical and biochemical sedimentary rocks is that in biochemical sedimentary rocks, organisms play a role in turning the ions into sediment. This means the presence and nature of biochemical sedimentary rocks are linked to the life requirements of the organisms that comprise them. In chemical sedimentary rocks, the process is inorganic, often resulting from a body of water evaporating and concentrating the ions. It is possible for one type of sedimentary rock to form from both chemical (inorganic) and biochemical (organically mediated) processes.

Chemical and biochemical sedimentary rocks are classified based on the minerals they contain, and are frequently dominated by a single mineral. It is true that some clastic sedimentary rocks, such as quartz arenite, can also be dominated by a single mineral, but the reasons for this are different. A clastic sedimentary rock can contain whatever minerals were present in the parent rock. The minerals the clastic rock ends up containing will depend on how much “processing” the sediments undergo by physical and chemical weathering, and transport, before the sediment was cemented. On the other hand, chemical sedimentary rocks are limited largely to those minerals that are highly soluble in water. Because mineral content is a defining characteristic of chemical and biochemical sedimentary rocks, we will use it to organize our discussion of these 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

Organic sedimentary rocks are those containing large quantities of organic molecules. Organic molecules contain carbon, but in this context we are referring specifically to molecules with carbon-hydrogen bonds, such as materials from the soft tissues of plants and animals. In other words, the carbon in calcite- $CaCO3$ wouldn't make calcite an organic mineral because it isn't bonded to hydrogen. An important organic sedimentary rock is coal. Most coal forms in swampy land adjacent to rivers and within deltas, and where climates are humid and tropical to temperate. The vigorous growth of vegetation leads to an abundance of organic matter that accumulates within stagnant, acidic water. This limits decay and oxidation of the organic material. If this situation—where the dead organic matter is submerged in oxygen-poor water—is maintained for centuries to millennia, a thick layer of material can accumulate. Limited decay will transform this layer into peat (Figure 9.18a, Figure 9.19 upper left).

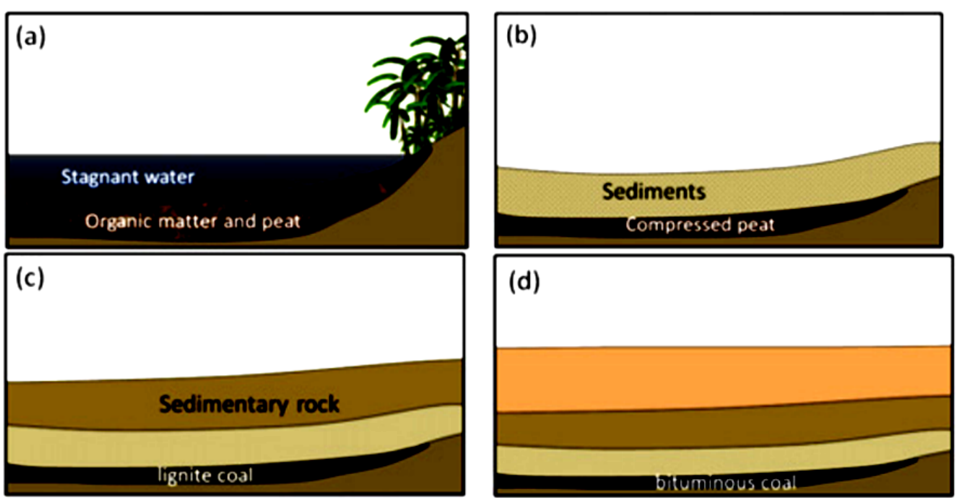


Figure 6.4: Formation of Coal

- The remains of plants and animals are buried under sediments, and due to heat and pressure from overlying layers, their composition changes. Coal and limestone are well-known examples.
- 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

- They are stratified —consist of many layers or strata.
- They hold the most informative geological records due to the marks left behind by various geophysical (weather patterns, wind and water flow) and biological activities (fossils).
- They are fossiliferous—have fossils of plants and animals.
- These rocks are generally porous and allow water to percolate through them.

The 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, the 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 the 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.

(iii) METAMORPHIC ROCKS

- The word metamorphic means ‘change of form’.
- Metamorphism is a process by which recrystallisation and reorganisation of minerals occur within a rock. This occurs due to pressure, volume and temperature changes.
- When rocks are forced down to lower levels by tectonic processes or when molten magma rising through the crust comes in contact with the crustal rocks, metamorphosis occurs.
- 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 an interplay of folding, warping 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.
- A magmatic intrusion causing thermal metamorphism is responsible for the peak of Mount 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 high 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 dynamo thermal metamorphism.
- Under high pressure, granite is converted into gneiss; clay and shale are transformed into schist.

Some examples of Metamorphosis

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

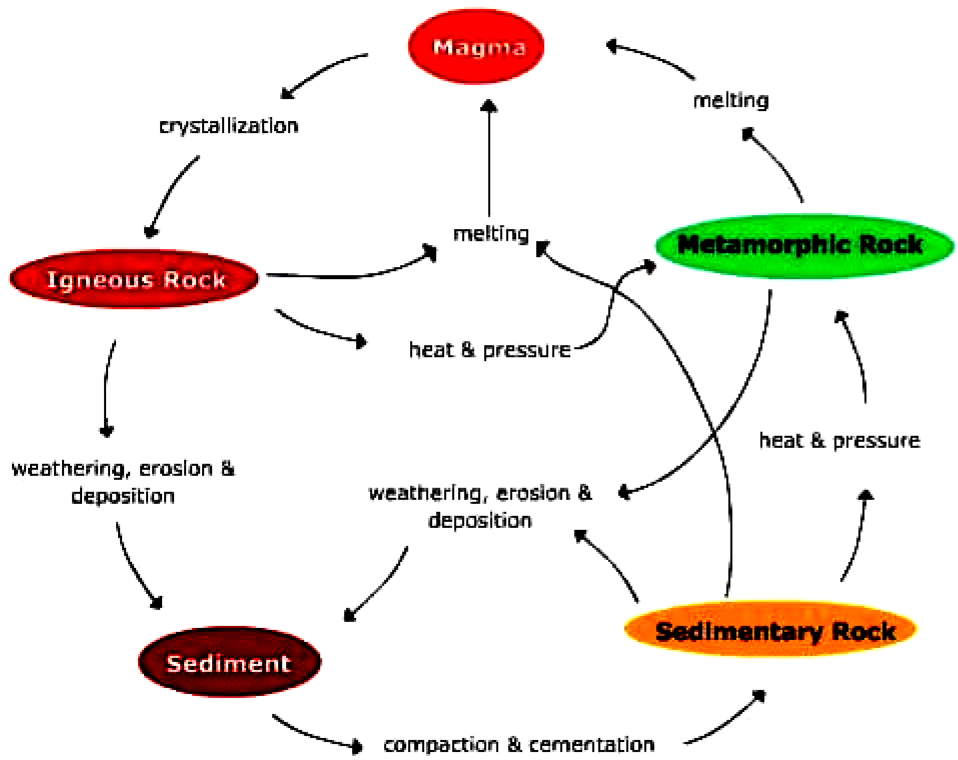
Metamorphic Rocks in India

- The gneisses and schists are commonly found in the Himalayas, Assam, West Bengal, Bihar, Orissa, Madhya Pradesh and Rajasthan.
- Quartzite is a hard rock found over Rajasthan, Bihar, Madhya Pradesh, Tamil Nadu and areas surrounding Delhi.
- 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 meltdown and turn into molten magma, the 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. It is used for ceramics and gloss making.
- Quartz: It has two elements, silicon and oxygen. It has a hexagonal crystalline structure. It is uncleaved, white or colourless. It cracks like glass and is present in sand and granite. It is used in the manufacture of radio and radar.
- Bauxite: A hydrous oxide of aluminium, it is the ore of aluminium. It is non-crystalline and occurs in small pellets.
- Cinnabar (mercury sulphide): 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.
- Gypsum: It is hydrous calcium sulphate and is used in cement, fertiliser and chemical industries.

- Haematite: It is a red ore of iron.
- Magnetite: It is the black ore (or iron oxide) of iron.
- Amphibole: It forms about 7 per cent of the earth's crust and consists mainly of aluminium, calcium, silica, iron, magnesium, etc. It is used in the asbestos industry.
- Mica: It consists of potassium, aluminium, magnesium, iron, silica, etc., and forms 4 % of the earth's crust. It is generally found in igneous and metamorphic rocks and is mainly used in electrical instruments.
- Olivine: The main elements of olivine are magnesium, iron and silica. It is normally a greenish crystal.
- Pyroxene: It consists of calcium, aluminium, magnesium, iron and silica. It is of green or black colour.
- Other minerals like chlorite, calcite, magnetite, hematite, bauxite, barite, etc., are also present in rocks.

MCQS.

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

Answers:

1) C. Silica and aluminium (Granite is an acidic igneous rock).

2) D. Foliation (E.g. Marble)

3) C. Mica is a group of silicate minerals; Graphite is a naturally-occurring form of crystalline carbon

4) B. Diamond is the hardest

5) D. Marble is a metamorphic rock

CHAPTER 9: FLUVIAL LANDFORMS

- The landforms created as a result of **degradational action (erosion and transportation)** or **aggradational works (deposition) of running water are** called fluvial landforms.

Fluvial Erosional Landforms

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

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

✓ **Corrosion:** chemical action that leads to weathering.

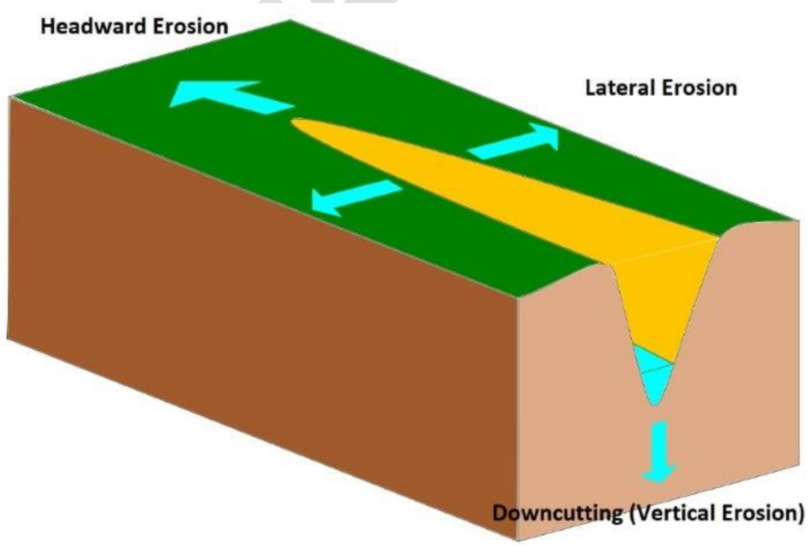
✓ **Attrition:** river load particles striking, colliding against each other and breaking down in the process.

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

✓ **Down cutting (vertical erosion):** the erosion of the base of a stream (down cutting leads to valley deepening).

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

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

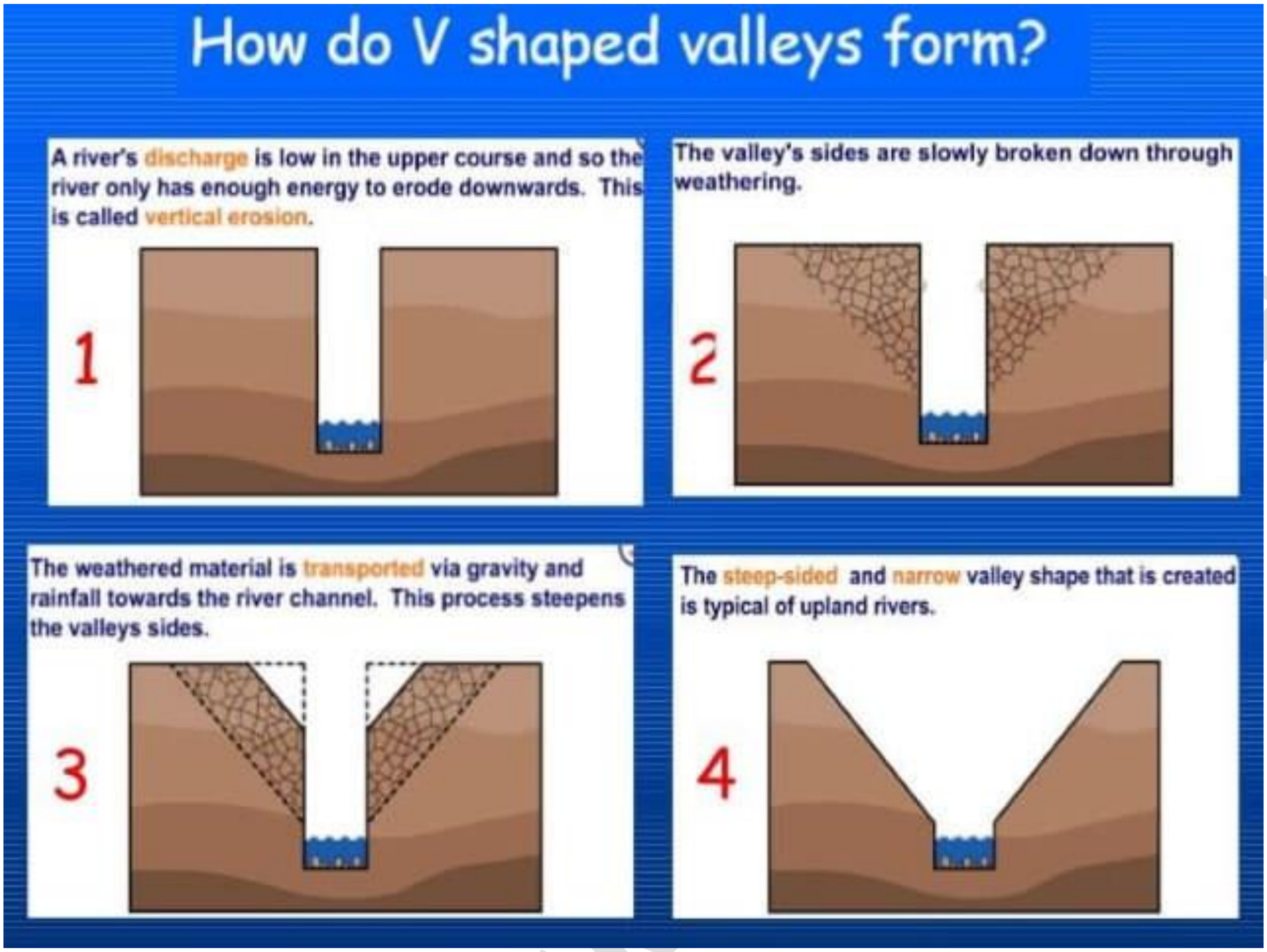


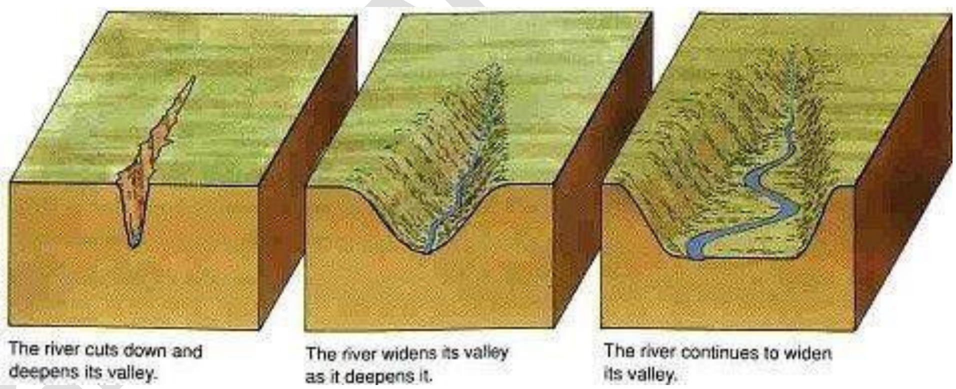
Vertical, Lateral and Headward Erosion (Kayau, from Wikimedia Commons)

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

River Valley Formation

- The extended depression on the ground through which a stream flows is called a river valley.
- At different stages of the erosional cycle, the valley acquires different profiles.
- At a young stage, the valley is deep, narrow with steep wall-like sides and a convex slope.
- The erosional action here is characterized by predominantly **vertical down cutting** nature.
- The profile of valley here is typically 'V' shaped.
- A deep and narrow 'V' shaped valley is also referred to as **gorge** and may result due to downcutting erosion or because of the recession of a waterfall (the position of the waterfall receding due to erosive action).
- Most Himalayan rivers pass through deep gorges (at times more than 500 metres deep) before they descend to the plains.
- An extended form of the gorge is called a **canyon.** The Grand Canyon of the Colorado River in Arizona (USA) runs for 483 km and has a depth of 2.88 km.
- A tributary valley lies above the main valley and is separated from it by a steep slope down which the stream may flow as a waterfall or a series of rapids.
- As the cycle attains maturity, the **lateral erosion** (erosion of the walls of a stream) becomes prominent and the valley floor flattens out (attains a 'V' to 'U' shape).
- The valley profile now becomes typically 'U' shaped with a broad base and a concave slope.


How do V shaped valleys form?
A river's discharge is low in the upper course and so the river only has enough energy to erode downwards. This is called vertical erosion.
1
The valley's sides are slowly broken down through weathering.
2
The weathered material is transported via gravity and rainfall towards the river channel. This process steepens the valleys sides.
3
The steep-sided and narrow valley shape that is created is typical of upland rivers.
4


The river cuts down and deepens its valley.
The river widens its valley as it deepens it.
The river continues to widen its valley.

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.
- E.g. Rivers flowing in the Himalayas.

Maturity

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

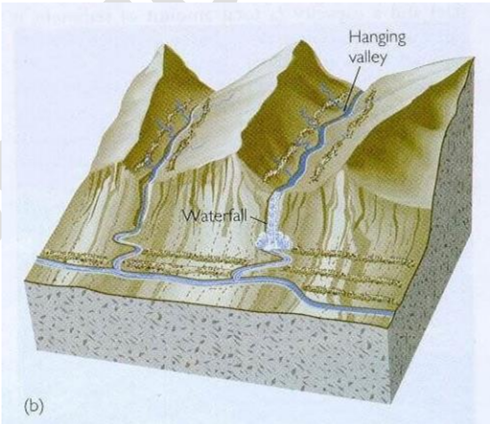
Old Age

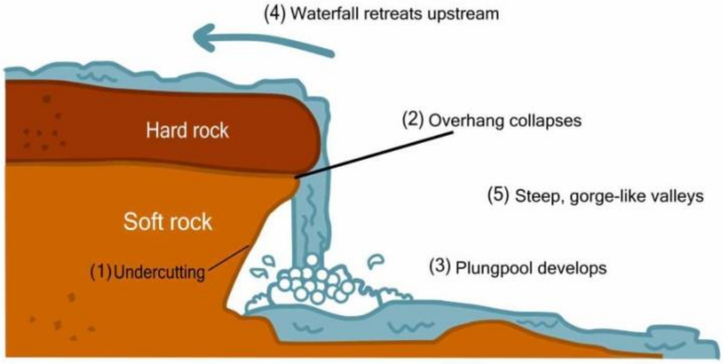
- At a river's mouth (C), sediment is deposited as the velocity of the river slows.
- As the river becomes shallower more deposition occurs, forming **temporary islands (Majuli, a river island in the Brahmaputra River, Assam is currently the world's largest river island)** and **braiding** (e.g. braided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

B. FLUVIAL EROSIONAL LANDFORMS:

Waterfalls

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





- **Kunchikal Falls** (it is a cascade falls — falls with many steps) formed by Varahi riverin Shimoga district, Karnataka is the highest waterfall in India (455 m).
- **Nohkalikai Falls (340 m)** is the tallest plunge waterfall in India. The waterfall is located near Cherrapunji.
- **Jog or Gersoppa falls (253 m)** on Sharavati river(a tributary of Cauvery), Karnatakais the second-highest plunge waterfall in India.
- **Angel Falls** in Venezuela is the world's highest waterfall, with a height of 979 metres and a plunge of 807 metres.
- **Tugela Falls** (948 m) in the Drakensberg mountains, South Africa is the world's second highest waterfall.

Potholes

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

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) floodplains.

Gulleys/Rills

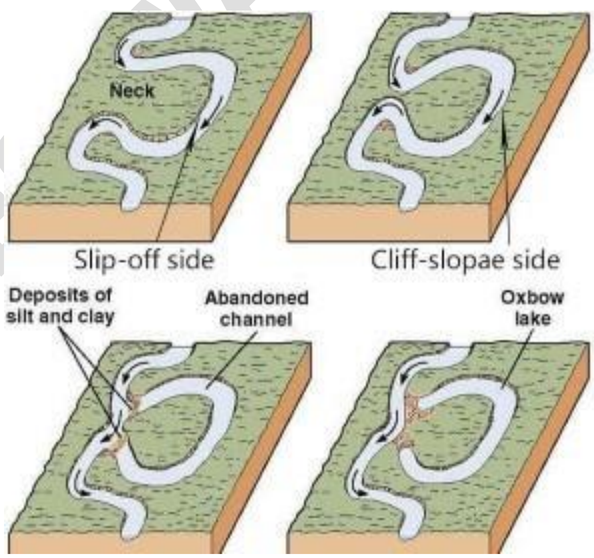
- Gulley is a water-worn channel, which is particularly common in semi-arid areas.
- It is formed when water from overland-flows down a slope, especially following heavy rainfall, is concentrated into rills, which merge and enlarge into a gulley.

- The **ravines of Chambal Valley** in Central India and the **Chos of Hoshiarpur** in Punjab are examples of gulleys.

Ravines of Chambal Valley in Madhya Pradesh

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.**
- The meanders may be wavy, horse-shoe type or oxbow type.



Oxbow Lake

- Sometimes, because of intensive erosion action, the outer curve of a meander gets accentuated to such an extent that the inner ends of the loop come close enough to get disconnected from the main channel and exist as independent water bodies called as oxbow lakes.

- These water bodies are converted into swamps in due course of time.

- In the Indo-Gangetic plains, southwards shifting of Ganga has left many oxbow lakes to the north of the present course of the Ganga.

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**.

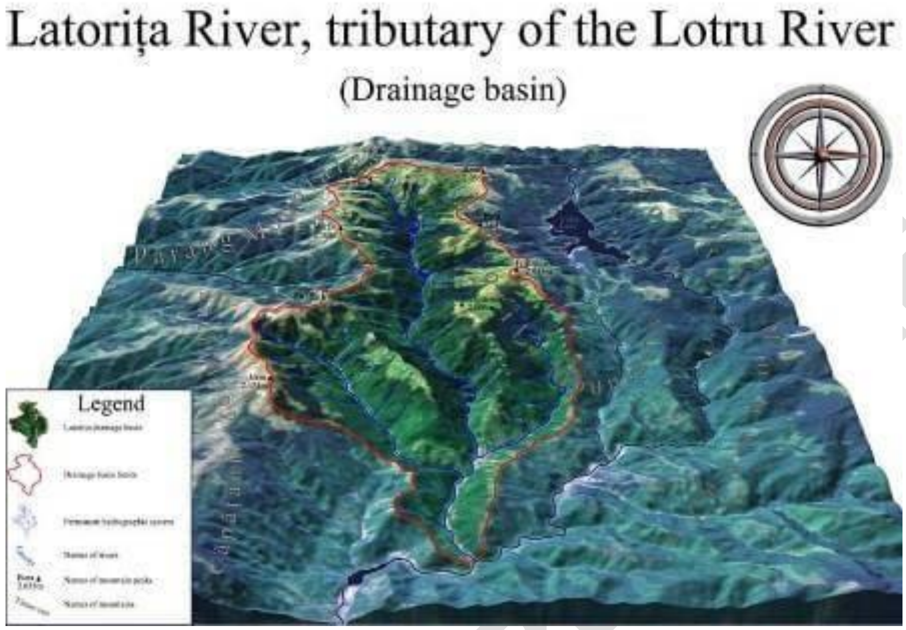
Uluru or Ayers Rock in central Australia standing on a peneplane

- Fluvial erosion, in the course of geologic time, reduces the land almost to base level (sea level), leaving so little gradient that essentially **no more erosion could occur**.

Drainage basin

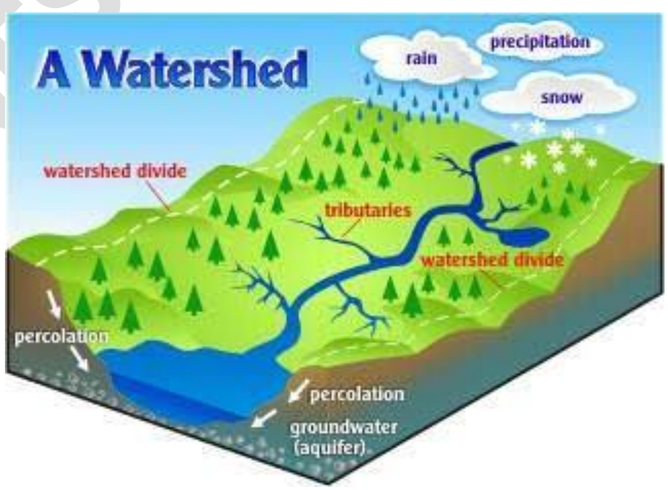
- Other terms that are used to describe drainage basins are **catchment, catchment area, catchment basin, drainage area, river basin, and water basin.**
- The drainage basin includes both the streams and rivers and the land surface.
- The drainage basin acts as a funnel by collecting all the water within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

- 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 (e.g. Lake Aral, also known Aral Sea, Dead Sea), dry lake (some desert lakes like Lake Chad, Africa), or a point where surface water is lost underground (sinkholes in Karst landforms).



Drainage Divide

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



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 + watershed of Chambal + watershed of Gandak + ... = Drainage basin of Ganga.

Some important drainage basins across the world

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

Drainage systems (drainage patterns)

- Drainage systems, also known as river systems, are the patterns formed by the streams, rivers, and lakes in a particular drainage basin.
- They are governed by tectonic irregularity, nature of underlying rock strata, and the gradient of the land.
- Based on the correlation between the topology and the direction of flow, drainage patterns are classified into concordant drainage and discordant or insequent drainage.

Concordant drainage

- 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 consequent, subsequent, obsequent and resequent.

Consequent Rivers

- The rivers which follow the **general direction of the slope** are known as the consequent rivers.
- Most of the rivers of peninsular India are consequent rivers.
- For example, rivers like the **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

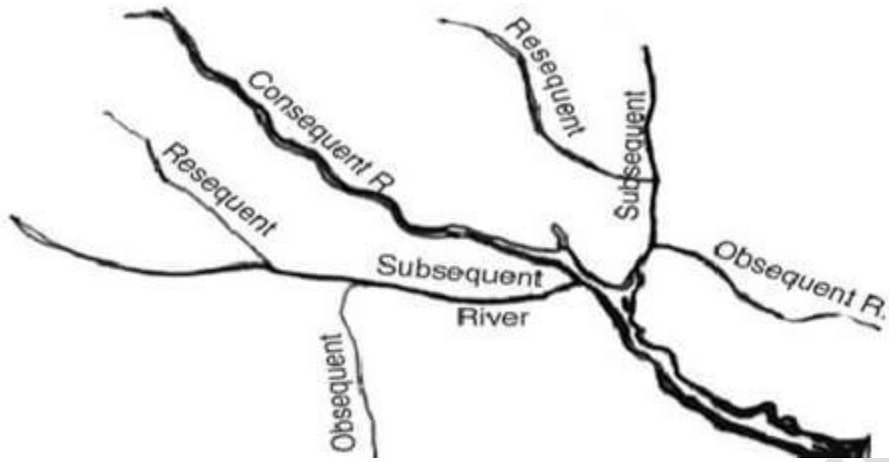
- A tributary stream that is formed by headward erosion **along** an underlying rock after the main drainage pattern (consequent river) has been established is known as a subsequent river.
- The **Chambal, Sind, Ken, Betwa, Tons and Son** meet the Yamuna and the Ganga at right angles. They are the subsequent drainage of the Ganga drainage system.

Obsequent Rivers

- After the valley development of consequent and subsequent rivers, obsequent rivers may form at right angles to the subsequent rivers and flow **opposite** to the direction of flow of the original consequent river.

Resequent Rivers

- A resequent river flows in the same direction as that of the initial consequent drainage.
- Resequent rivers originate at a much later stage (hence they are called resequent) in comparison to the master consequentrivers.



Discordant or Insequent drainage patterns

- A drainage pattern is described as discordant if it **does not correlate to the topology (surface relief features)** and **geology**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**.
- Usually, rivers in both these drainage types flow through a **highly sloping surface**.

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) 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 **antecedent rivers (rivers older than the existing land itself)**.

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.

Explanation

- 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 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 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 wasbeing 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.
- [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: *cuts through the newly formed landform and maintains the same path. E.g. Himalayan Rivers.*

Superimposed Drainage: *cuts deeper through the existing landform and maintains the same path. E.g. some medium scale rivers of the Northern and Eastern peninsular India.*

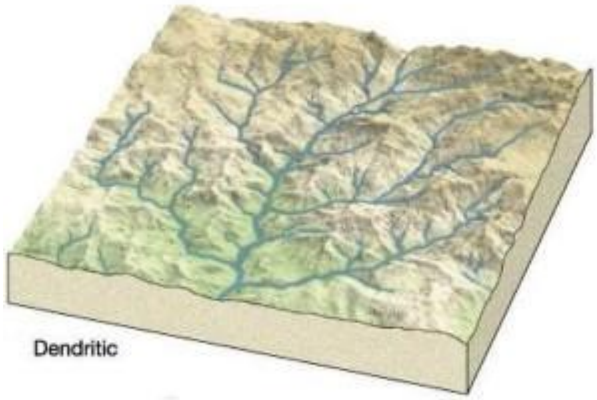
Antecedent Drainage: *The soil formed is weak (mostly weak sediments), andthe rivers easily erode it.*

Superimposed Drainage: *The rivers have high erosive power so that they can cut through the underlying strata.*

Other Drainage Patterns

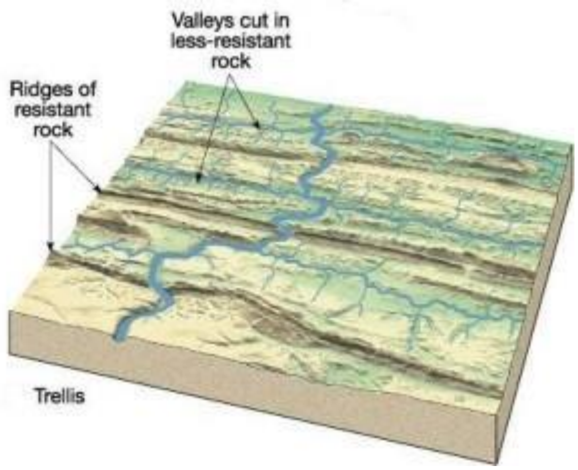
Dendritic or Pinnate Drainage Pattern

- This is an irregular tree branch shaped pattern that develops in a terrain which has uniform lithology (uniform rock structure), and where faulting and jointing are insignificant.
- Examples**: Indus, Godavari, Mahanadi, Cauvery, Krishna.**



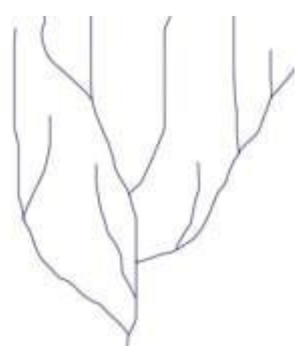
Trellis Drainage Pattern

- 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 drainage of trellis pattern.



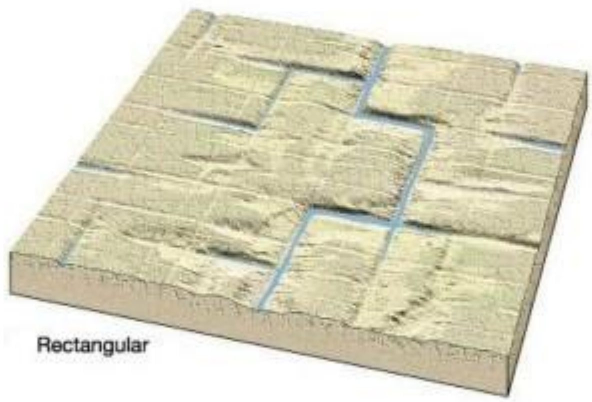
Angular Drainage Pattern

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



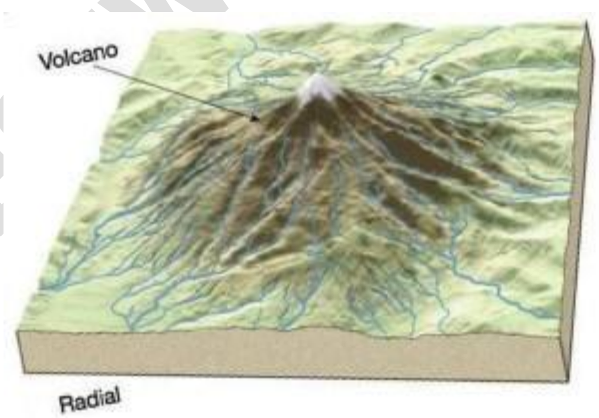
Rectangular Drainage Pattern

- 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.



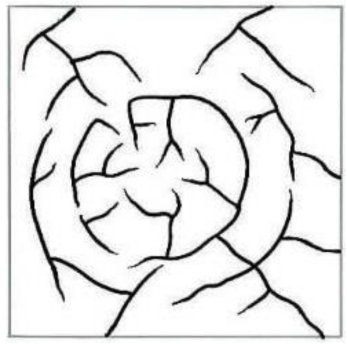
Radial Drainage Pattern

- The tributaries from a summit follow the slope downwards and drain down in all directions.
- Examples: **Streams of Saurashtra region,** the **rivers originating from the Amarkantak Mountain, Central French Plateau, Mt. Kilimanjaro**.
- The Narmada, Son and Mahanadi originate from Amarkantak Hills and flow in different directions.



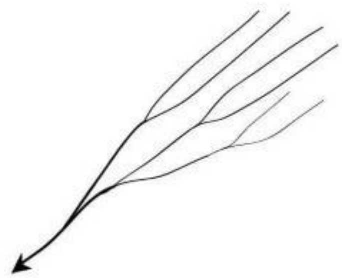
Annular Drainage Pattern

- When the upland has a soft outer stratum, the radial streams develop subsequent tributaries which try to follow 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**.



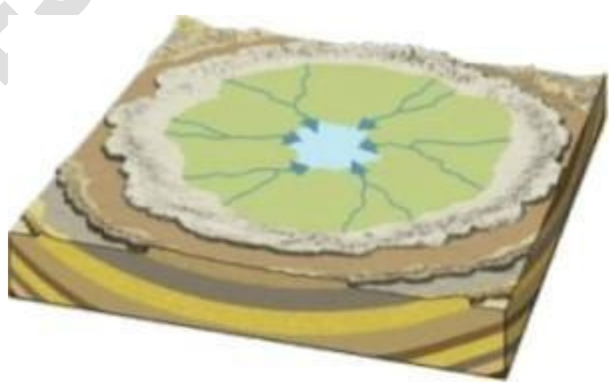
Parallel Drainage Pattern

- 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.



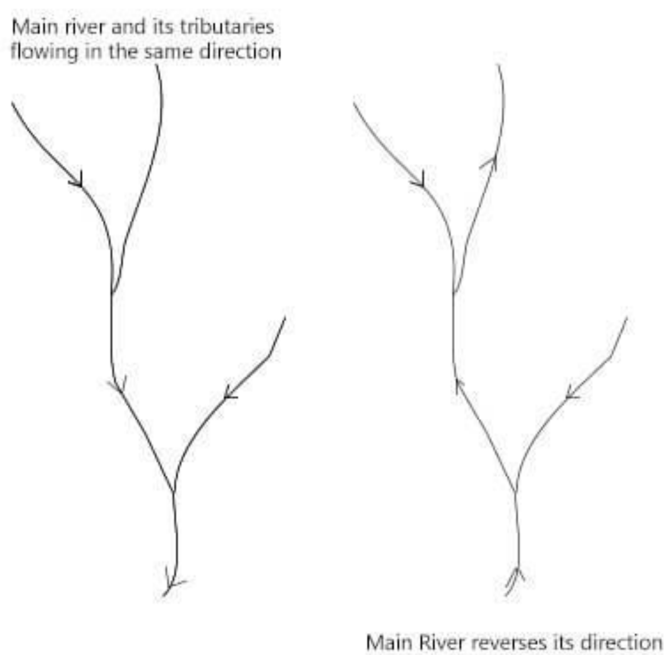
Deranged Drainage Pattern

- This is an uncoordinated pattern of drainage characteristic of a region recently vacated by an ice-sheet.
- The picture is one of the numerouswatercourses, lakes and marshes; some inter-connected and some in local drainage basins of their own.

- 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 the 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.



B. FLUVIAL DEPOSITIONAL LANDFORMS:

- Fluvial Depositional Landforms are landforms created by the depositional activity of rivers.
- 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.
- Various landforms resulting from fluvial deposition are as follows:

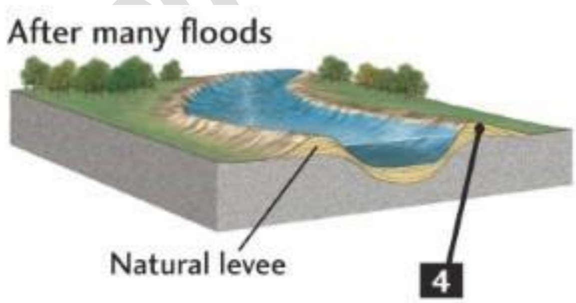
Alluvial Fans and Cones

- 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 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**.



Poit bars:

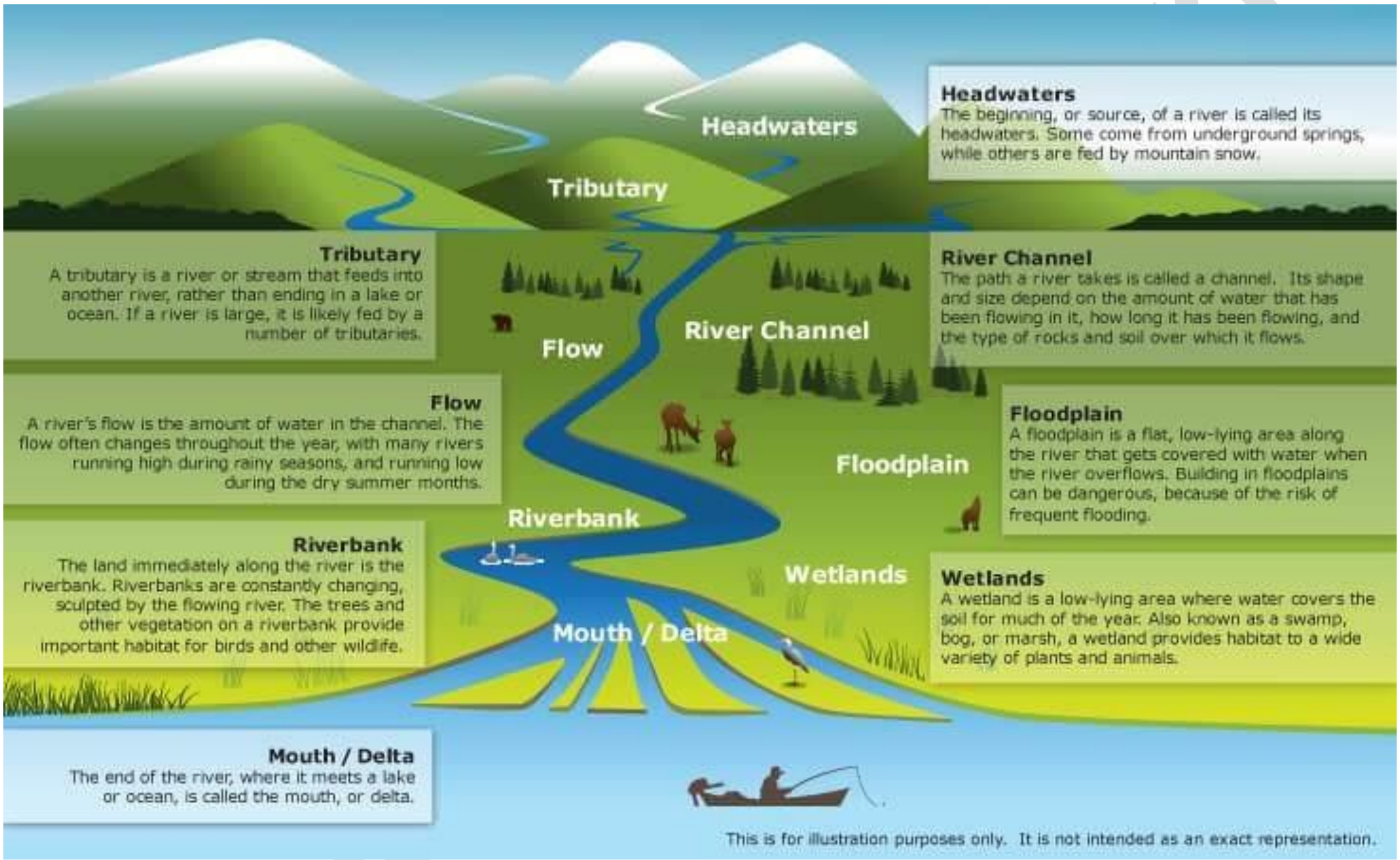
A **point bar** is a depositional feature made of alluvium that accumulates on the inside bend of streams and rivers below the slip-off slope. **Point bars** are found in abundance in mature or meandering streams.

Distributaries:

A **distributary**, or a **distributary channel**, is a stream that branches off and flows away from a main stream channel. Distributaries are a common feature of river deltas. The phenomenon is known as river bifurcation. The opposite of a distributary is a tributary. Distributaries are found where a stream nears a lake or an ocean. They can also occur inland, on alluvial fans, or where a tributary stream bifurcates as it nears its confluence with a larger stream. In some cases, a minor distributary can divert so much water from the main channel that it can become the main route.

Delta

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



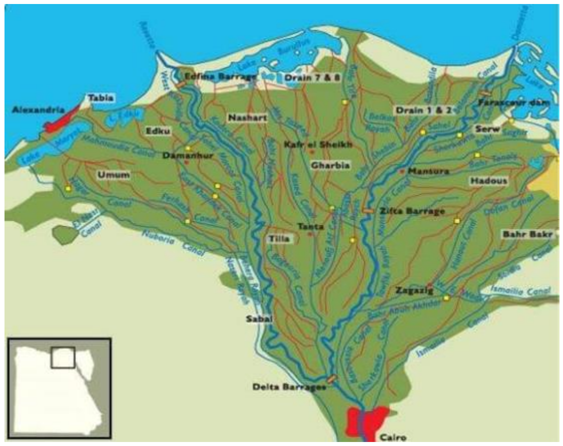
A combination of two processes forms a delta:

1. the 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)

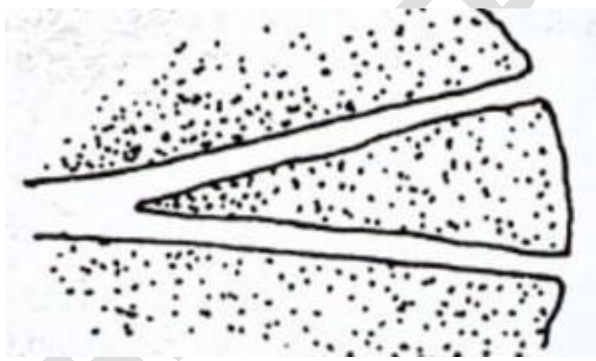
- This type of delta emerges when limestone sediment deposits do not allow downward seepage of water.
- The distributaries seem to be flowing over projections of these deposits which appear as a bird's foot.
- The currents and tides are weak in such areas and the number of distributaries lesser as compared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

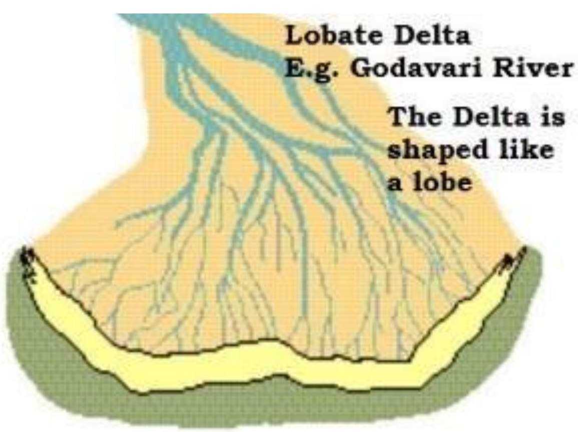
Cuspate Delta

- This is a pointed delta generally formed 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 the 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**.
- The Godavari River represents lobate delta.



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 (arcuate) of deltas

- Both of these types have a large sediment supply that tends to disperse sediment along the shoreline.
- A lobate delta (a subtype 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 seawater (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.

CHAPTER 10: AEOLIAN LANDFORMS

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

Wind is a geomorphic agent in all terrestrial environments. Work of wind causes aeolian processes including erosion, transportation, and deposition. Wind erodes and moves a variety of materials and further deposits them at a greater distance from their source area. The ability of erosion and transportation by wind mainly depends on particles weight, size and shape. The flat shaped particles move very slowly compared to the rounded grains. Aeolian particles are generally round in shape than those of glacial and fluvial environments. Wind transports sand-sized particles and silt that can travel as dust storms over distances of thousands of kilometres. Turbulent winds are supposed to lift large quantities of fine dust into the air forming a dense high cloud called a dust storm. Standing within the dust cloud, one seems to be shrouded in deep gloom or even total darkness.

(i) Erosion

Deflation is the process of removing talus on the earth surface by wind, while **corrasion** is the physical weathering of rock by talus-carrying wind. The process of removing, lifting and blowing away the unconsolidated sand and dust particles by wind is called deflation. Deflation is accomplished mainly by air currents. Wind carries the enormous quantity of sand and small angular rock fragments as tools of erosion, and these particles attack rocks and soil surfaces in the form of sand blasting. As a result, the rock surfaces are smoothened and polished. This process is called aeolian abrasion. Corrasion processes include abrasion, chipping and polishing. The disintegrated rock particles are transported by the wind they not only strike against the rocks standing on their way but also collide against each other. The gradual reduction in the size of rock particles by mutual friction and forceful contact they break down further into small particles, finer sand and dust. This process is called **attrition**.

(ii) Transportation

The stages of transportation depend on the wind velocity and sediment load. Wind has the ability and force to lift the Earth's unconsolidated sand, silt and dust sized particles by the mechanisms mentioned like saltation or rolling and traction/creeping and suspension.

(iii) Deposition

Wind carries forward sediments and particles once picked by it from any source on the surface for a varying distance depending on its carrying capacity. Deposition of material carried away by wind can take place at any place and time. The settling and deposition of wind borne material takes place when there are obstructions. All these create constructive aeolian landforms. Wind is an effective agent for sorting of materials according to their shape, size and weight. Decrease in velocity of wind results in deposition of windblown sediments which are highly sorted in nature.

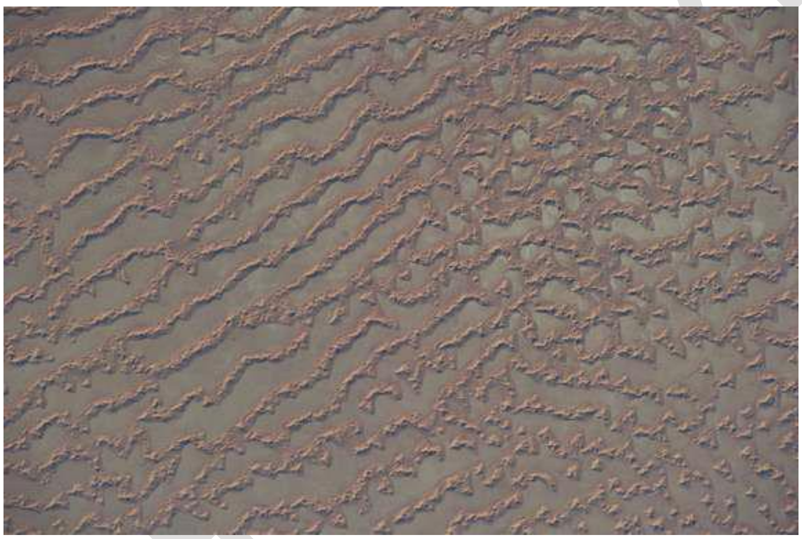
Wind deposition can take place due to following reasons:

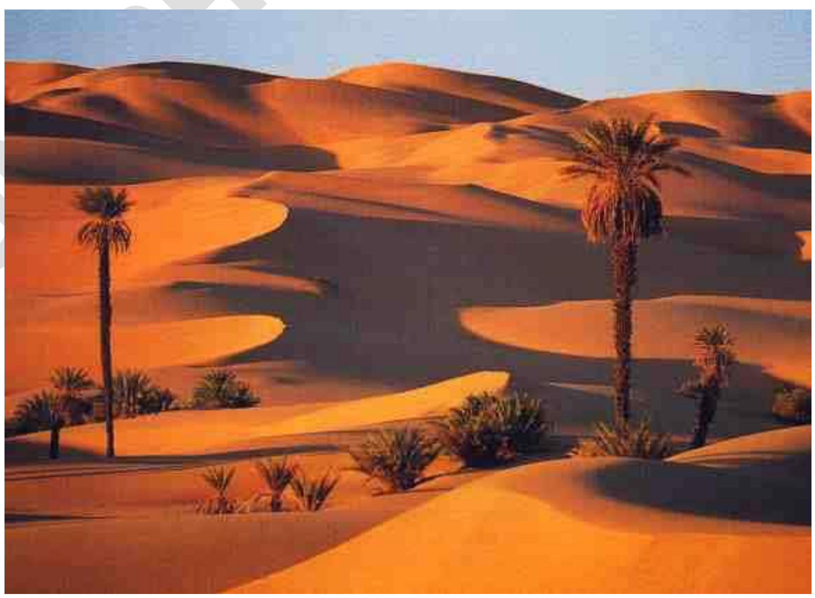
- obstruction in movement of wind like hill, mountains, buildings, forest belts, vegetation, etc;
- reduction in wind velocity; and
- increase in moisture content and precipitation (rainfall and snowfall)

Wind is a good sorting agent. Depending upon the velocity of wind, different sizes of grains are moved along the floors by rolling or saltation and carried in suspension and in this process of transportation itself, the materials get sorted. When the wind slows or begins to die down, depending upon sizes of grains and their critical velocities, the grains will begin to settle. Therefore, good sorting of grains can be found in depositional landforms made by wind. More formally, wind will deposit its talus load when its supply of kinetic energy is too low to carry the talus mass. Since a desert has an abundant supply of sand and with nearly constant wind directions prevailing, depositional features in arid regions can develop anywhere.
The three commonly distinguished landforms formed by wind deposition of talus are **draas, dunes** and **ripples**.

Draas and ergs

Draas are huge sand accumulations and where these converge, a landform termed **erg** is formed – such as the star-shaped Great Continental Erg in Algeria. There are approximately twenty ergs in the Sahara, which collectively cover about 15% of the Sahara's surface area.





These '**sand seas'** are extensive accumulations of sand up to 300 m thick and are essentially water deposits, while most of them occupy large depressions which are former (paleo) lakes or shallow oceans, which were subsequently filled with water-borne (i.e. fluvial) talus. The surface of the draas are shaped by wind – with dunes typically developing on the wind side. On a smaller scale, individual ripples are formed on the surface of a draa or dune. All three of these wind-shaped landforms, draas, dunes and ripples, are in essence waves – and can therefore be described in terms of their geometric characteristics like wavelength and amplitude.

Sand Dunes

Dry hot deserts are good places for sand dune formation. Obstacles to initiate dune formation are equally important. **Dune form**, i.e. their shape and size, is **controlled or determined** by three factors, namely the **strength and direction of wind**, the **amount of sand available** and the **amount (if any) of vegetation present**. All dunes are mobile to some extent, and can be classified into live dunes and fixed dunes on the basis of their mobility.

A. AEOLIAN (OR) ARID EROSIONAL 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 blowouts.
- 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 kilometres 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 many 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 the 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.

B. AEOLIAN (OR) ARID DEPOSITIONAL LANDFORMS

- The depositional force of wind also creates landforms. These are as follows.

Ripple Marks

- These are depositional features on a small scale formed by saltation (the 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.

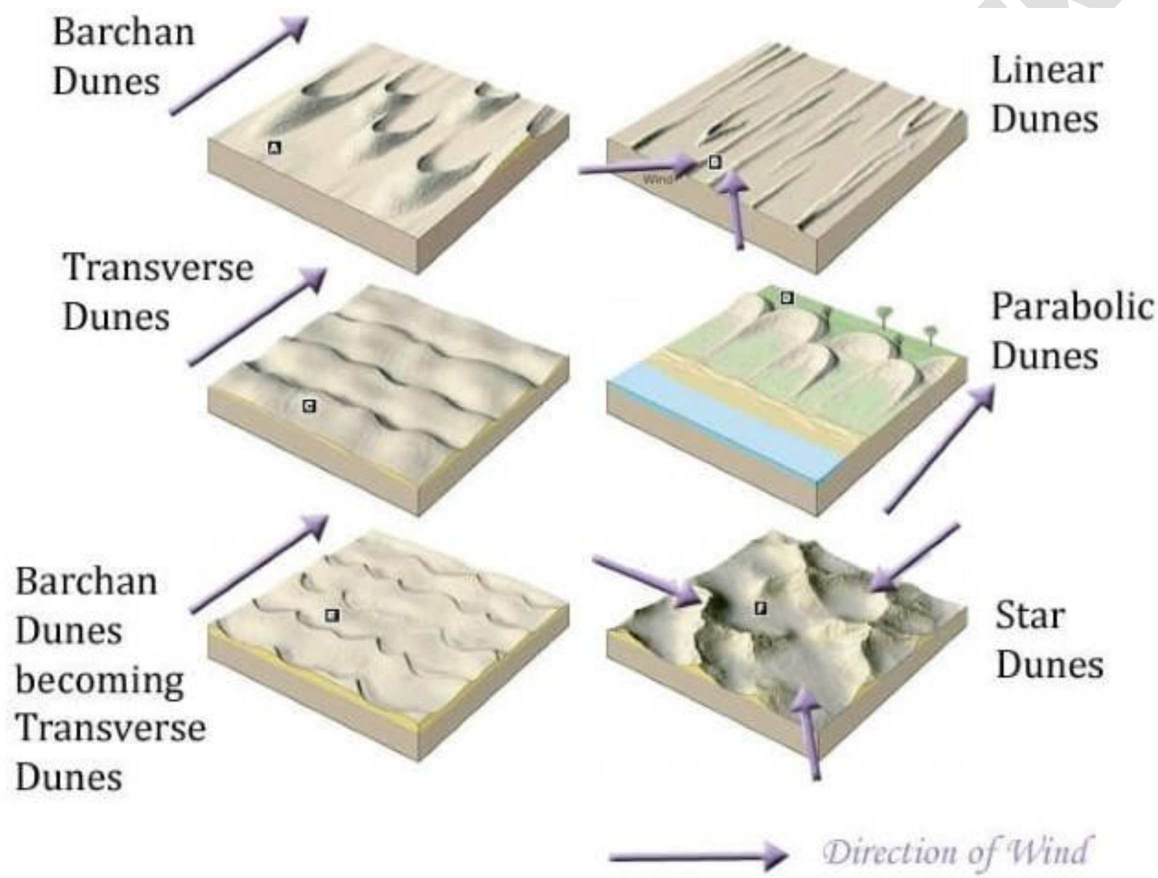
Some of the forms are discussed below:

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

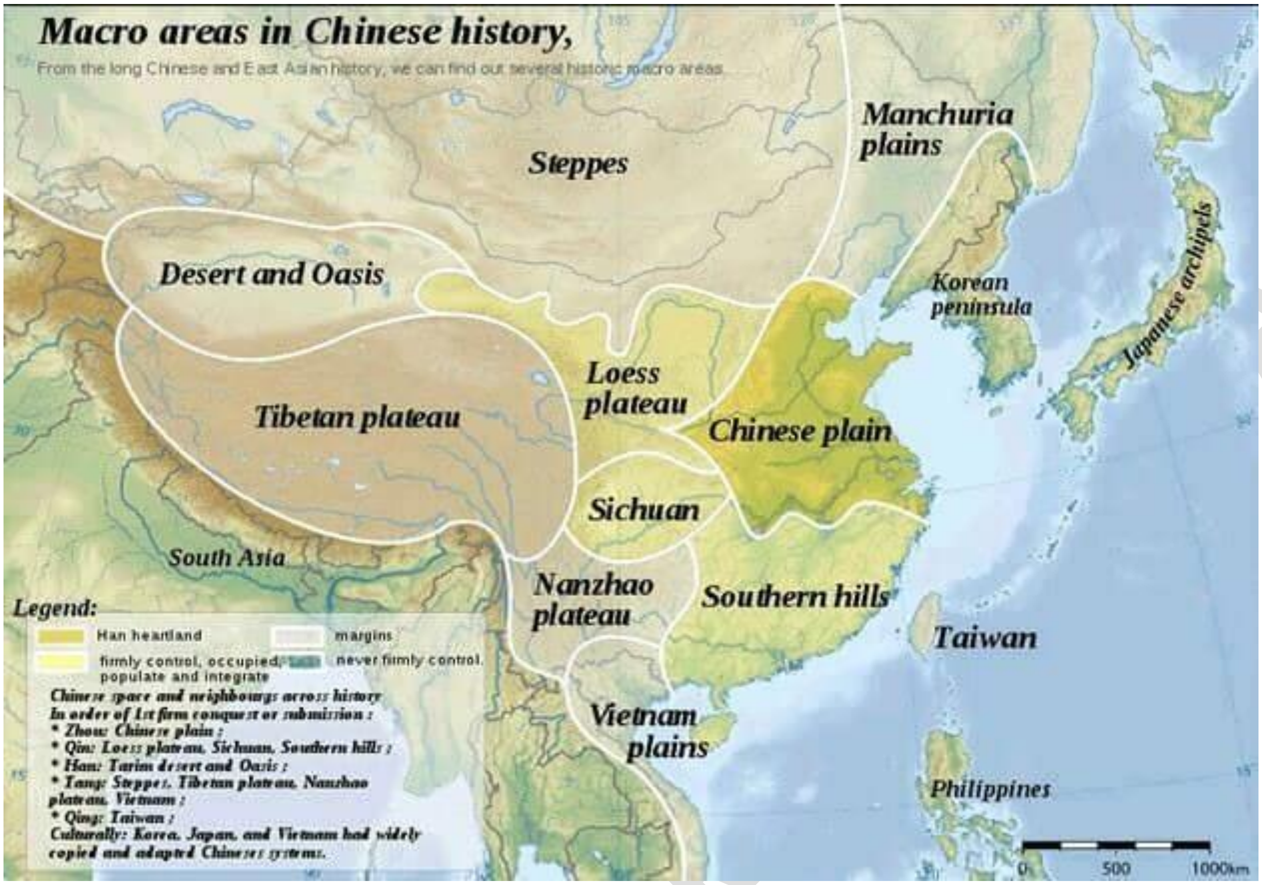
- They are U-shaped and are much longer and narrower than barchans.

Star dunes

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

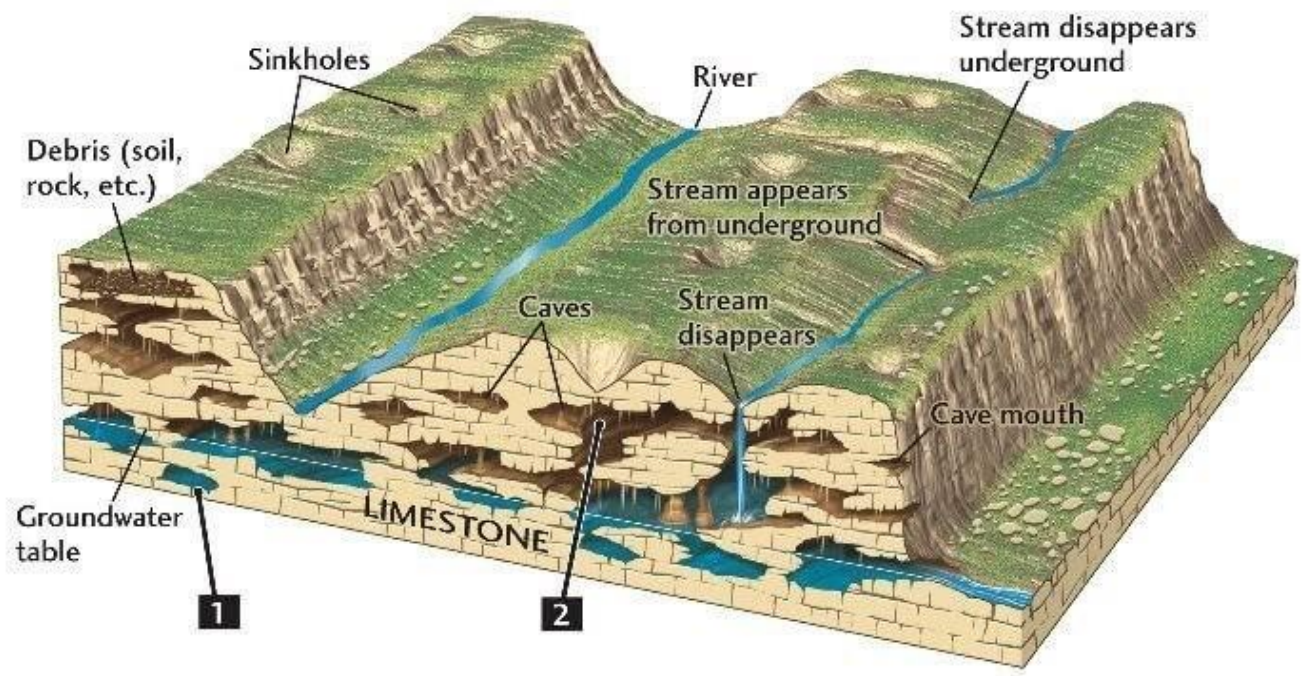
Loess

- 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 the 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.


Macro areas in Chinese history,
From the long Chinese and East Asian history, we can find out several historic macro areas
Steppes
Manchuria plains
Desert and Oasis
Korean peninsula
Japanese archipels
Loess plateau
Tibetan plateau
Chinese plain
Sichuan
South Asia
Nanzhao plateau
Southern hills
Taiwan
Vietnam plains
Philippines
Legend:
Han heartland
margins
firmly control, occupied, populate and integrate
never firmly control.
Chinese space and neighbourgs across history
In order of 1st firm conquest or submission :
* Zhou: Chinese plain ;
* Qin: Loess plateau, Sichuan, Southern hills ;
* Han: Tarim desert and Oasis ;
* Tang: Steppes, Tibetan plateau, Nanzhao plateau, Vietnam ;
* Qing: Taiwan ;
Culturally: Korea, Japan, and Vietnam had widely copied and adapted Chineses systems.
0 500 1000km

CHAPTER 11: KARST LANDFORMS: EROSION AND DEPOSITION

- Karst landforms are characterized by **underground** drainage systems with sinkholes, fissures, caves formed from the dissolution (chemical weathering) and erosion of soluble rocks such as limestone, dolomite.
- There is the general absence of surface drainage as the water flow is mostly subsurface (underground).
- In its pure state, limestone is made up of calcium carbonate, but where magnesium is also present, it is termed as dolomite.
- Limestone is an organically formed sedimentary rock (formed by the decomposition of calcareous shells) and is soluble in rainwater.
- The carbonic acid that causes karstic features is formed as rain passes through the atmosphere picking up carbon dioxide (CO_2).
- Once the rain reaches the ground, it may pass through soil that can provide much more CO_2 to form a weak carbonic acid solution, which dissolves calcium carbonate (limestone).
- Karsts are so named after a province of **Yugoslavia** (in Balkans) **on the Adriatic Sea** coast where such formations are most noticeable.



Conditions for the formation of karst topography:

- Surface or subsurface strata made up of porous water-soluble rocks such as limestone.
- Thinly bedded and highly jointed and cracked rock strata that make it easy for the water to seep in.
- Moderate to abundant rainfall for chemical weathering of limestone.
- A perennial source of water and a low water table to erode the weathered rock.

A. KARST TOPOGRAPHY: EROSIONAL LANDFORMS:

Sinkhole/Swallow Hole

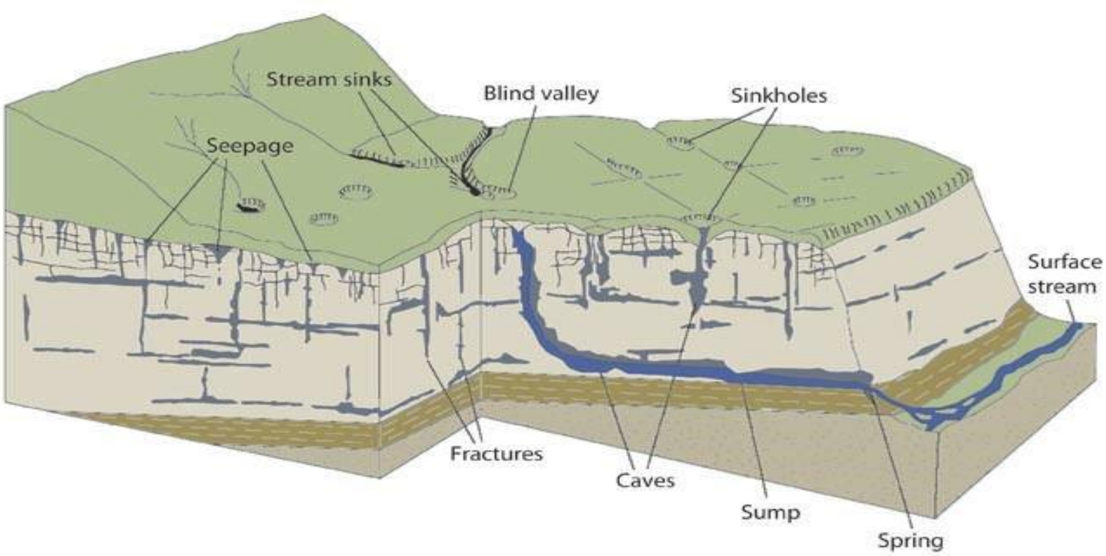
- Sinkholes are funnel-shaped depressions developed by enlargement of the cracks found in porous water-soluble rocks, as a result of continuous solvent action (chemical weathering) of the rainwater.
- The surface streams disappear underground through swallow holes.
- There is a great variation in size and depth of sinkholes.

Karst Window

- When some adjoining sinkholes collapse, they form an open, broad area called a karst window.

Polje/Blind Valley

- Dolines are small depressions dotting a karst landscape. They are less common than sinkholes
- Some adjoining dolines may come together to form a long, narrow trench called uvala.



- Someuvalas may coalesce to create a 'U' shaped valley called polje.
- If the streams lose themselves in these valleys, then these are called blind valleys.

Cavern

- This is an underground cave formed by water action by various methods in a limestone stratum.
- Mechanical action by rock debris and pebbles and solution action of water may be responsible for cavern formation.
- In India, such caves can be seen in Bastar, Dehradun, Shillong plateau.

Arch/Natural Bridge

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

Sinking Creeks/Bogas

- In a karst 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.

B. KARST TOPOGRAPHY: DEPOSITIONAL LANDFORMS

Stalactite and Stalagmite

- When water containing limestone seeps through the roof in the form of a continuous chain of drops a small deposit of limestone is left behind due to evaporation of water contributing to the formation of a lean inverted cone-like structure growing downwards from the roof called stalactite.
- 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.

Dry Valley/Hanging Valley/Bourne

- Sometimes, a stream erodes so much that it goes very deep. The water table is also lowered. Now the tributaries start serving the subterranean drainage and get dried up. These are dry valleys or bournes.
- Lack of adequate quantities of water and reduced erosion leaves them hanging at a height from the main valley. Thus, they are also referred to as hanging valleys.

C. THE KARST CYCLE OF EROSION

Youth

- Youth begins with the surface drainage on an initial limestone surface.
- Gradually, the upper impervious layer is eroded.
- Dolines, sinkholes and swallow holes are formed.
- No large caverns exist, and underground drainage has not yet completed its course.

Maturity

- There is maximum underground drainage.
- Surface drainage is limited to short-sinking cracks ending in swallow holes or blind valleys.
- Cavern networks are characteristic of this stage.
- Late maturity marks the beginning of the decline of karst features.
- The portions of cavern streams are exposed through karst windows. These expand to form large uvalas, and detached areas of original limestone upland begin to stand out as hums.

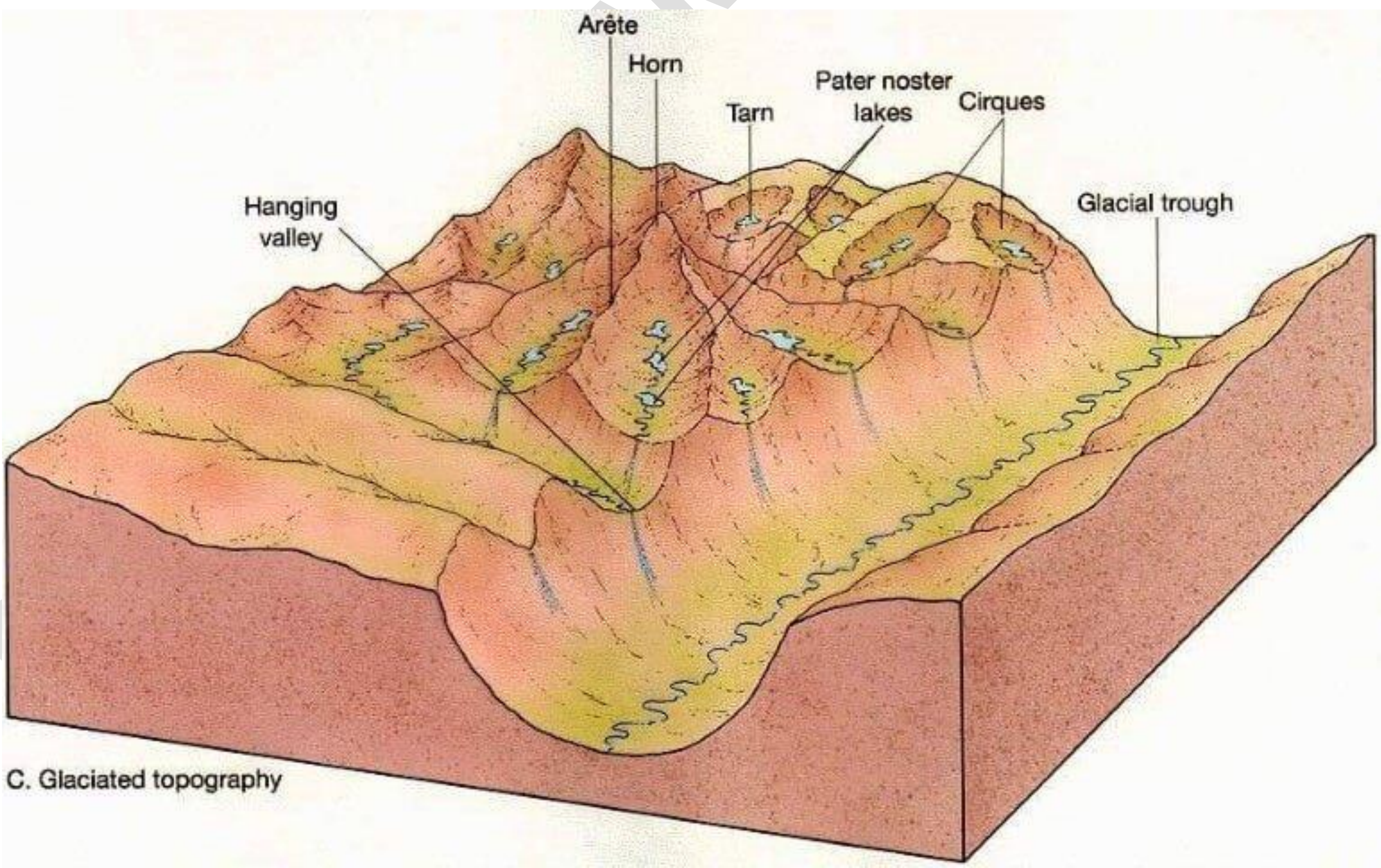
Old Age

- Large-scale removal of limestone mass leaves behind a karst plain.
- There is a reappearance of surface drainage with only a few isolated hums as remnants of the original limestone terrain.

CHAPTER 12: GLACIAL TOPOGRAPHY AND LANDFORMS

- A glacier is a moving mass of ice at speeds averaging a few meters a day.
- Types of Glaciers: **continental glaciers, ice caps, piedmont glaciers and valley glaciers**.
- The continental glaciers are found in Antarctica and 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.

A. GLACIAL TOPOGRAPHY: EROSIONAL LANDFORMS



Cirque/Corrie

- Hollow basin cut into a mountain ridge.
- It has a 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 is at a 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

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

D-Fjord

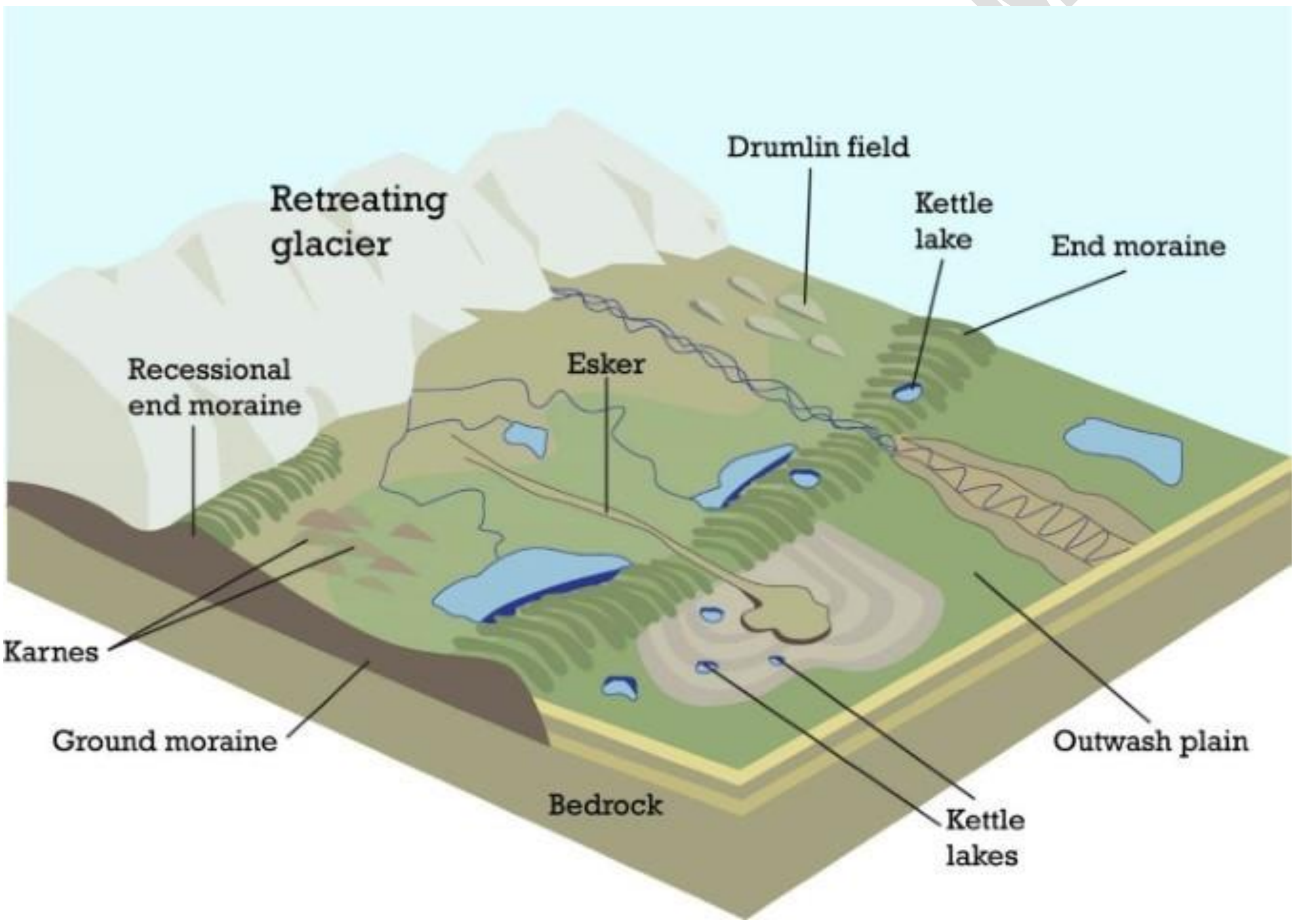
- Steep-sided narrow entrance-like feature at the coast where the stream meets the coast.
- Fjords are common in **Norway, Greenland and New Zealand**.

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

- Ice and glacier coverage at lower altitudes in cold climates is more important than the collision of tectonic plates. (Glacial erosion is very strong because of the huge boulders of rocks carried by the glacial ice that graze the surface. Though ice moves only a few meters a day, it can take along it huge rocks that can peel 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.

B. GLACIAL TOPOGRAPHY: 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

- Kame terraces form when sediment accumulates in ponds and lakes trapped between lobes of glacier ice or between a glacier and the valley side.

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

- The 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.

C. 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

- The 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.

Module 01: Atmosphere: Evolution, Composition and Structure

Earth is a unique planet because the life is found only on this planet. The air has a special place among the conditions necessary for life. The air is a mixture of several gases. The air encompasses the earth from all sides. The air surrounding the Earth is called the atmosphere. The atmosphere is an integral part of our Earth. It is connected with the earth due to the gravitational force of the earth. It helps in stopping the ultra violet rays harmful for the life and maintain the suitable temperature necessary for life.

1.0 Introduction: The earth is an exclusive planet among eight planets of our solar system because the is the only planet which comprises life on it. The necessary conditions required for life on earth includes air, water and land and air occupies a special place among them. The air is an assortment of various gases. The entire planet earth is enveloped by a deep blanket of gases extending several thousands of kilometres above the surface of the earth. This gaseous cover of the earth is called as the atmosphere. The atmosphere is an integral part of our earth. It is made up of several gases, water vapour and minute particles suspended in the gaseous substance of air. With out this atmosphere, we can not survive. All our daily activities are confined with it. Like land (lithosphere) and water (hydrosphere), the atmosphere is also an integral part of the earth and it is held in place by the gravitational influence of earth.

The atmosphere as part of the crust

To the Earth scientist, the crust includes not only the top layer of solid material (soil and rocks to a depth of 6 to 70 km [4 to 44 miles], separated from the underlying mantle by differences in density and by susceptibility to surficial geologic processes) but also the hydrosphere (oceans, surface waters on land, and groundwater beneath the land surface) and the atmosphere. Interactions among these solid, liquid, and gaseous portions of the crust are so frequent and thorough that considering them separately introduces more complexities than it eliminates. As a result, a description of the history of the atmosphere must concern itself with all volatile components of the crust.

Materials

Volatile compounds as well as elements important in present and past atmospheres or in interactions between the atmosphere, biosphere, and other portions of the crust include the following:

1. Present major components: molecular nitrogen (N_2) and molecular oxygen (O_2)
2. Noble gases: helium (He), neon (Ne), argon (Ar), krypton (Kr), and xenon (Xe)
3. Abundant variable components: water vapour (H_2O) and carbon dioxide (CO_2)
4. Other components: molecular hydrogen (H_2), methane (CH_4), carbon monoxide (CO), ammonia (NH_3), nitrous oxide (N_2O), nitrogen dioxide (NO_2), hydrogen sulfide (H_2S), dimethyl sulfide [$(CH_3)_2S$], sulfur dioxide (SO_2), and hydrogen chloride (HCl).

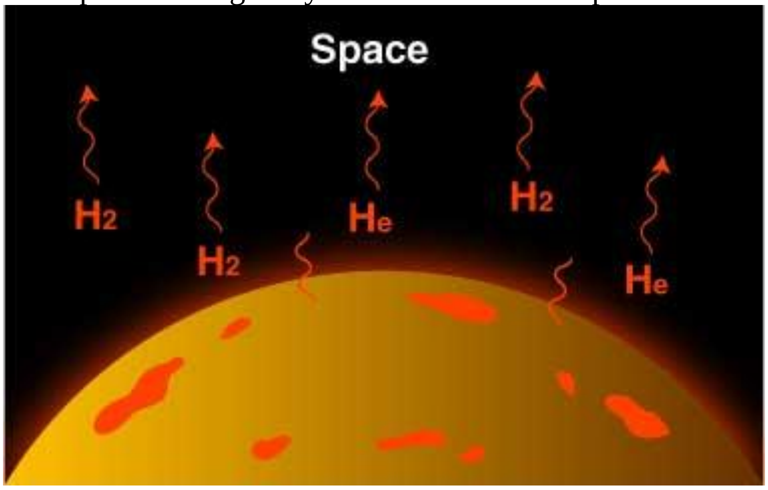
1.1 Evolution of Earth's atmosphere

In the 4.6 billion years of Earth's history, the composition of the atmosphere has changed from a hazy, unfamiliar mix to today's mostly blue skies. As the atmosphere developed, life began and evolved. The evolution of living things changed the atmosphere, and those changes in turn altered life. As far as we know, the relationship is unique to our planet.

- The first atmosphere consisted of gases in the solar nebula, primarily hydrogen. For your convenience this part is divided into four headings which are:
  - **i. Hadean eon (4,540 – 4,000 mya): The primordial atmosphere**
  - **ii. Archean eon (4000 mya – 2500 mya)**
  - **iii. Proterozoic Eon (2500 mya – 541 mya): Oxygen in atmosphere**
  - **iv. Phanerozoic Eon (541 mya to present): The present atmosphere**

1.1.1 Hadean eon (4,540 – 4,000 mya): The primordial atmosphere

- Earth’s original atmosphere was probably just hydrogen and helium, because these were the main gases in the dusty, gassy disk around the Sun from which the planets formed. The Earth and its atmosphere were very hot. Molecules of hydrogen and helium move really fast, especially when warm. Actually, they moved so fast they eventually all escaped Earth's gravity and drifted off into space.



*During the **Late Heavy Bombardment** (4 billion years ago), a disproportionately large number of asteroids have collided with the early terrestrial planets including earth.*

- Over time, the Earth’s surface solidified leaving behind hot volatiles which resulted in a **heavy CO_2 atmosphere** with hydrogen, nitrogen, inert gases and water vapour.
- After the formation of oceans, **dissolving in ocean water removed most CO_2 from the atmosphere**.
- Some CO_2 reacted with metals to form carbonates that were deposited as sediments.
- The early atmosphere contained almost **no oxygen**.
- Most of the lighter gases like the hydrogen and helium escaped into space and are continually escaping even to the present day due to **atmospheric escape** (outer layers stripped by solar wind).

1.1.2 Archean eon (4000 mya – 2500 mya)

- The atmosphere was **without oxygen,** and the atmospheric pressure was around **10 to 100 atmospheres**.
- Nitrogen formed the major part of the then stable "second atmosphere".

- Earth’s “second atmosphere” came from Earth itself. There were lots of volcanoes, many more than today, because Earth’s crust was still forming. The volcanoes released
  - steam (H_2O, with two hydrogen atoms and one oxygen atom),
  - carbon dioxide (CO_2, with one carbon atoms and two oxygen atoms),
  - ammonia (NH_3, with one nitrogen atom and three hydrogen atoms).
- **Outgassing of the solid planet**
- The release of gases during volcanic eruptions is one example of outgassing; releases at submarine hydrothermal vents are another. Although the gas in modern volcanic emanations commonly derives from rocks that have picked up volatiles at earth’s surface and then have been buried to depths at which high temperatures remobilize the volatile material, a very different situation must have prevailed at the earliest stages of Earth’s history.

(The planet accreted from solid particles that formed as the primordial gas cloud cooled. Long before the volatile components of the cloud began to condense to form massive solid phases (that is, long before water vapour condensed to form ice), their molecules would have coated the surfaces of the solid particles of rocky material that were forming. As these solid particles continued to grow, a portion of the volatiles coating their surfaces would have been trapped and carried thereafter by the particles. If the solids were not remelted by impact as they collected to form the planet, the volatiles they carried would have been incorporated in the solid planet. In this way, even without collecting an enveloping gaseous atmosphere, a newly formed planet could include—as material occluded in its constituent grains—a substantial inventory of volatiles.)

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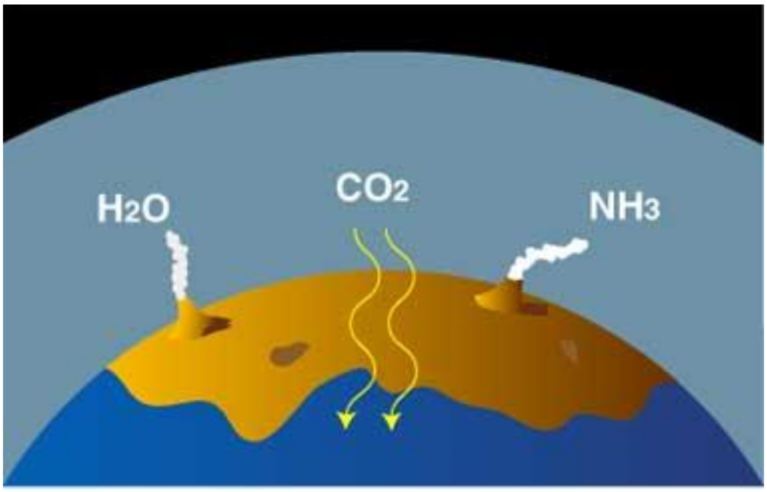
- **Volcanic out gassing** created the primordial atmosphere.
- Out gassing from volcanism, supplemented by gases produced during the late heavy bombardment of Earth, produced the next atmosphere.



- Most of the nitrogen in the air was carried out from deep inside the earth by volcanoes.
- In the late Archean Eon, an oxygen-containing atmosphere began to develop, apparently produced by photosynthesising cyanobacteria.
- The constant re-arrangement of continents influenced the long-term evolution of the atmosphere by transferring carbon dioxide to and from large continental carbonate stores.

1.1.3 Proterozoic Eon (2500 mya – 541 mya): Oxygen in atmosphere

- Free oxygen did not exist in the atmosphere until about 2.4 billion years ago.
- O_2 showed major variations until reaching a steady state of more than 15% by the end of the Proterozoic.

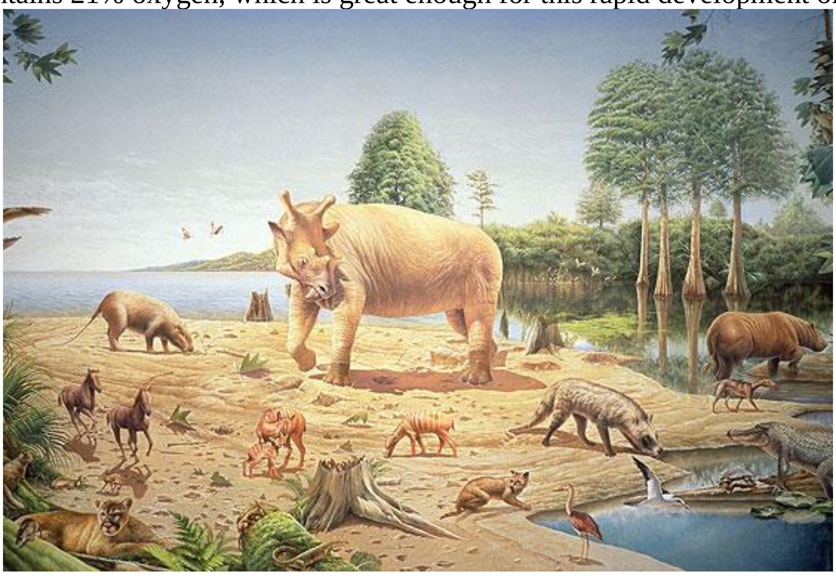
- Between 700-550 million years ago, in the late Proterozoic, oxygen levels in the oceans and atmosphere increased dramatically. By 600 million years ago, the oxygen in the atmosphere reached about one-fifth of today's level (21 percent). The oxygen boom favored the evolution of lifeforms that could use oxygen to create energy. For other organisms, oxygen was poisonous, and they were forced into extreme airless habitats or into extinction. Some scientists say that the increase in oxygen helped fuel the burst of sea life known as the Cambrian explosion, 530 to 509 million years ago, including the evolution of *eurypterid*s and trilobites.

Late Carboniferous Period (Pennsylvanian)
318-299 million years ago

- Until about 430 million years ago, most aerobic organisms lived in the ocean and used oxygen dissolved in seawater. Then about 430 million years ago, life on land appeared. Small plants and invertebrates (animals without backbones) evolved the ability to live on land and use oxygen directly from the atmosphere. During the Devonian Period, 416-397 million years ago, plants evolved, as did the first four-footed animals.
-

1.1.4 Phanerozoic Eon (541 mya to present): The present atmosphere

- The amount of oxygen reached a peak of about 30% around 280 million years ago.
- Two main processes govern changes in the oxygen levels in the atmosphere:
  1. Plants use carbon dioxide from the atmosphere, releasing oxygen.
  2. Breakdown of **pyrite (iron sulphide)** and **volcanic eruptions** release **sulphur** into the atmosphere, which oxidises and hence **reduces the amount of oxygen in the atmosphere**. However, volcanic eruptions also release carbon dioxide, which plants can convert to oxygen.
- Periods with much oxygen in the atmosphere are associated with rapid development of animals.
- Today's atmosphere contains 21% oxygen, which is great enough for this rapid development of animals.



1.2 Composition of Atmosphere

The cover of atmosphere around our planet earth, a mechanical combination of several gases and additional substances are very significant to all living organisms of the planet.

for your suitability this section is divided into 3 major points which are

1.2.1 Gases

1.2.2 Liquids

1.2.3 Solids

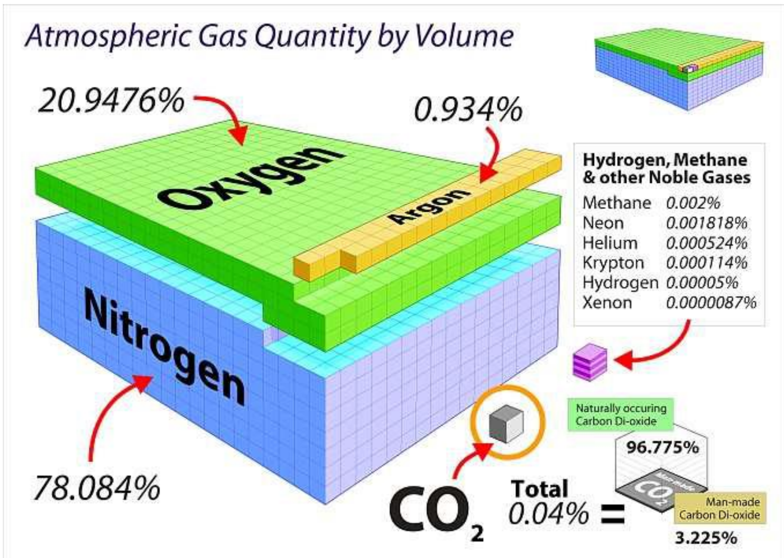
1.2.1 Gases:

- The composition of Earth's atmosphere is largely governed by the by-products of the life that it sustains.
- The table on the screen shows you that Dry air from Earth's atmosphere contains **78.08% nitrogen, 20.95% oxygen, 0.93% argon, 0.04% carbon dioxide**, and traces of hydrogen, helium, and other noble gases.
- The four foremost gases – nitrogen, oxygen, argon and carbon dioxide collectively account 99.99 percent of the total volume of dry air.
- The highest concentration is of nitrogen with more than 78 percent while the oxygen is about 21 percent.
- The remaining gases are often referred to as trace gases, among which are the greenhouse gases, principally **carbon dioxide, methane, nitrous oxide**, and **ozone**.
- Various industrial pollutants also may be present as gases or **aerosols**, such as chlorine, fluorine compounds and elemental mercury vapour.
- Sulphur compounds such as hydrogen sulphide and sulphur dioxide (SO_2) may be derived from natural sources or industrial air pollution.

1.2.1.1 Permanent Gases of the Atmosphere

Name	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
Methane (CH_4)	**0.000179**
Xenon (Xe)	0.00009
Hydrogen (H_2)	0.00005

- Permanent atmospheric gases remain in fixed proportion to the total gas volume.
- Other constituents, such as methane, neon, helium, krypton, hydrogen and xenon, vary in quantity from place to place and from time to time (fig).
- Heavier gases like nitrogen and oxygen tend to stick at the bottom of the atmosphere.
- 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.



1.2.1.2 Important constituents of the atmosphere

Oxygen

- All living organisms inhale oxygen.
- Besides, oxygen can combine with other elements to form important compounds, such as, oxides.
- Also, **normal combustion is not possible without oxygen**.

Nitrogen

- 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, i.e., it prevents spontaneous combustion of oxygen in the atmosphere.
- It also indirectly helps in oxidation of different kinds.

Carbon Dioxide

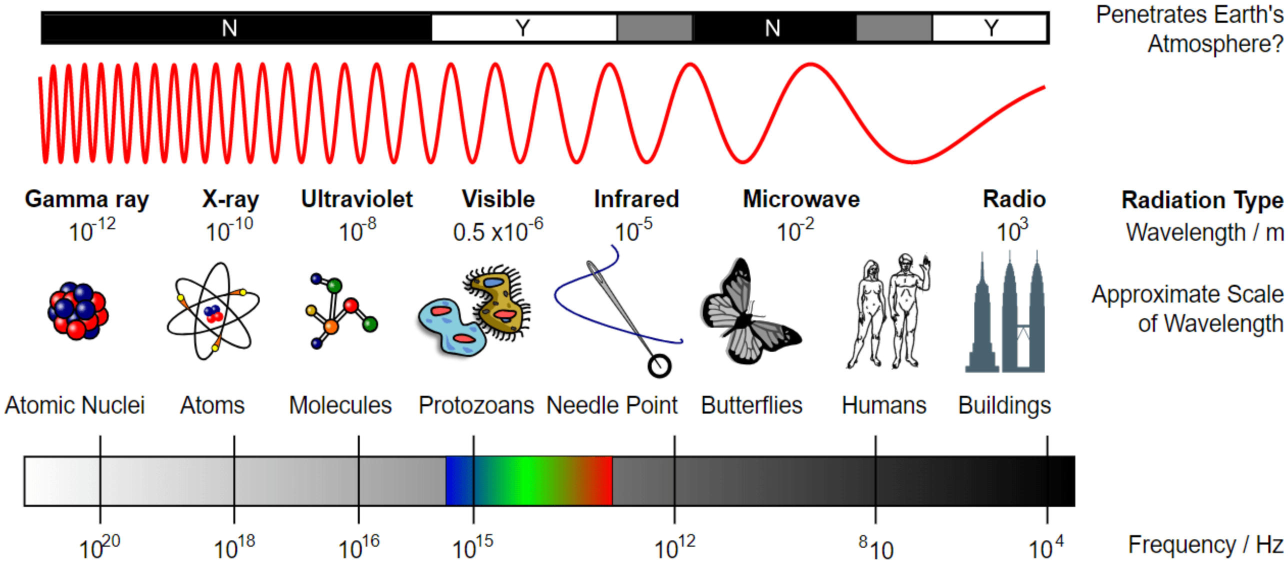
- Green plants, through photosynthesis, absorb carbon dioxide from the atmosphere.
- Being an **efficient absorber of heat**, carbon dioxide is a very important factor in the **heat energy budget**.
- With increased burning of fossil fuels – oil, coal and natural gas – the carbon dioxide percentage in 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 (O_3)

- Ozone (O_3) is a type of oxygen molecule consisting of three oxygen atoms.
- It forms less than 0.00005% by volume of the atmosphere and is **unevenly distributed**.
- It is between 20 km and 30 km altitude (**stratosphere**) that the greatest concentrations of ozone are found.
- It is **formed at higher altitudes (due to interaction between O_2 and UV light)** and transported downwards.
- Ozone plays a crucial role in **blocking the harmful ultraviolet radiation** from the sun.

1.2.2 Liquids or 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 short-wave solar radiation (visible and UV radiation)**.



Electromagnetic Spectrum (Inductiveload, via Wikimedia Commons)

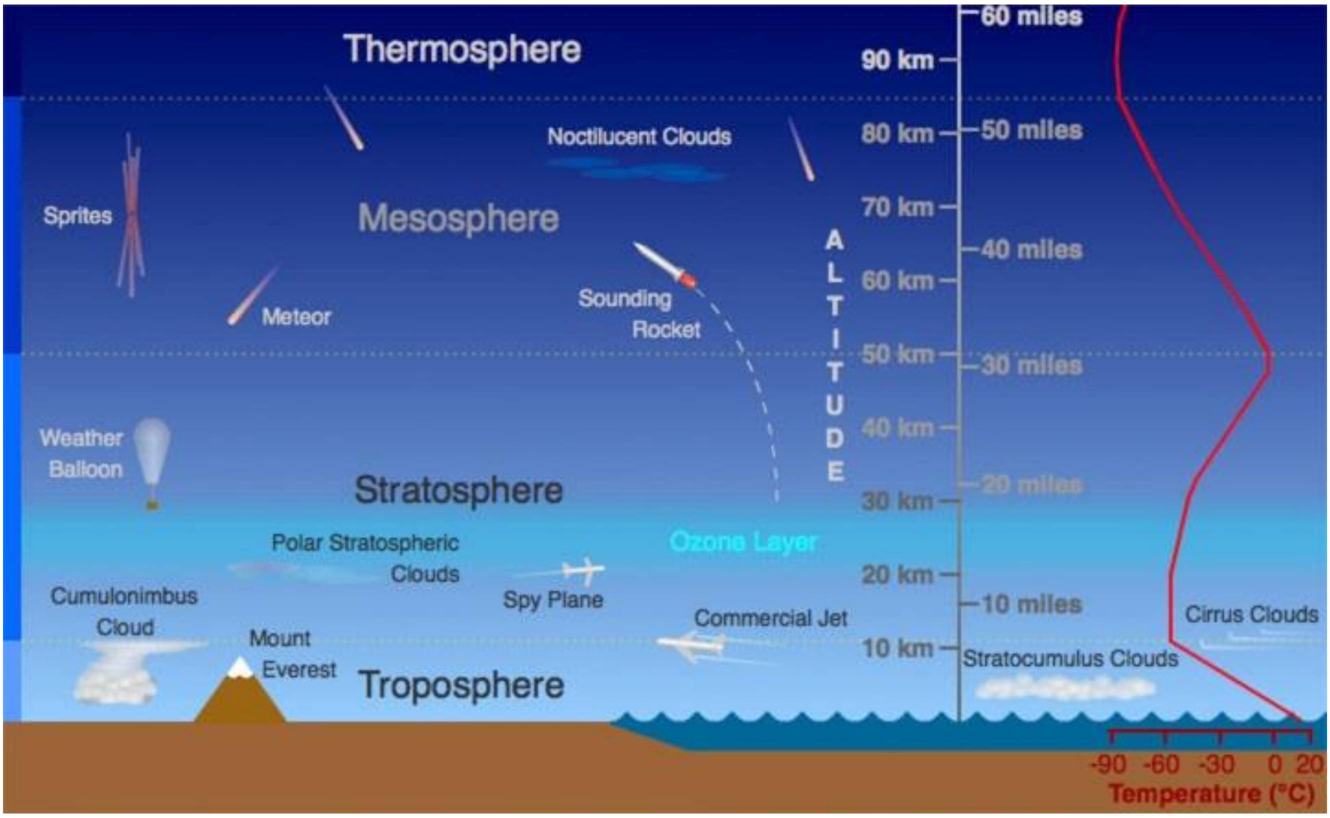
- Water vapour is the source of precipitation and clouds.
- On condensation, it releases **latent heat of condensation** —the ultimate driving force behind all storms.

1.2.3 Solid Particles

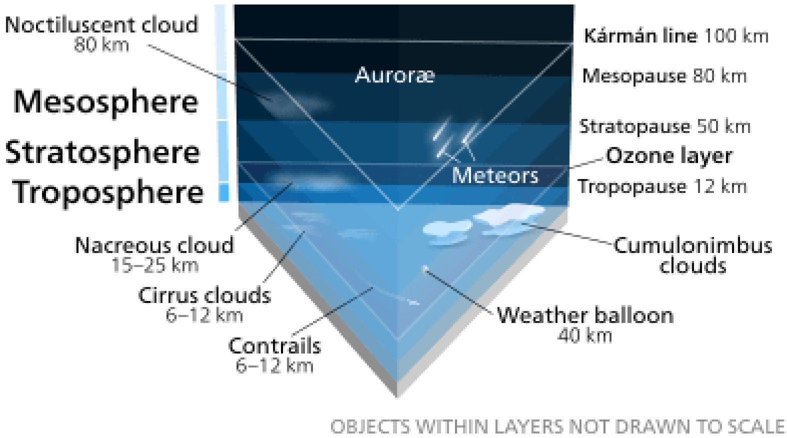
- The Solid Particles present in the atmosphere consist of sand particles (from weathered rocks and also derived from volcanic ash), pollen grains, small organisms, soot, ocean salts; the upper layers of the atmosphere may even have fragments of meteors which got burnt up in the atmosphere.
- These solid 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 **refraction** 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 and different forms of precipitation, fog and hailstones**, etc.

1.3 STRUCTURE OF ATMOSPHERE

- The atmosphere can be studied as a layered entity – each layer having its peculiar characteristics. These layers are systematically discussed below.
  1. **Troposphere: 0 to 18 km**
  2. **Stratosphere: 18 to 50 km**
  3. **Mesosphere: 50 to 80 km**
  4. **Thermosphere: 80 to 800 km**
  5. **Exosphere: above 800 km**



Layers of the atmosphere (Wikimedia Commons)



Layers of the atmosphere (Kelvinsong, Wikimedia Commons)

1.3.1 Troposphere

- Its altitude is 8 km at the poles and 18 km at the equator.
- The **thickness is greater at the equator because of the heated air that rises to greater heights**.
- The troposphere ends with the Tropopause.
- The temperature in this layer, as one goes upwards, **falls** (positive lapse rate) at the rate of **6.5 °C per kilometre**.
- It is -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 troposphere is marked by temperature inversion, turbulence and eddies.
- It is also meteorologically the most significant zone in the entire atmosphere (all weather phenomena like cyclones, rainfall, fog and hailstorm etc. are confined to this layer).
- It is also called the convective region since **all convection stops at Tropopause**.

Tropopause

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

1.3.2 Stratosphere

- It lies beyond tropopause, 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 (negative lapse rate) 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, the aeroplanes fly in lower stratosphere, sometimes in upper troposphere where weather is calm.
- Sometimes, **cirrus clouds** are present at lower levels in this layer.

1.3.2.1 Ozonosphere

- It lies at an altitude between 20 km and 55 km from the earth's surface and spans the stratosphere and lower mesosphere. But the **highest concentration occurs between 20 km and 30 km**.
- Because of the presence of ozone molecules, **this layer absorbs and reflects the harmful ultraviolet radiation**.
- The **temperature rises** (negative lapse rate) at a rate of 5° C per kilometre through the ozonosphere.
- The ozonosphere is also called **chemosphere** because of a lot of chemical activity taking place.
- Ultraviolet light splits O_2 into individual oxygen atoms (atomic oxygen); the atomic oxygen then combines with unbroken O_2 to create ozone, O_3.
- The ozone molecule is unstable (although, in the stratosphere, long-lived) and when ultraviolet light hits ozone it splits into a molecule of O_2 and an individual atom of oxygen (**ozone-oxygen cycle**).
- Stratospheric ozone depletion is caused by chlorofluorocarbons, bromofluorocarbons and other ozone-depleting substances that increase the concentrations of **chlorine** and **bromine radicals**.
- Each of these radicals initiates and catalyses a chain reaction capable of breaking down over 100,000 ozone molecules.

1.3.3 Mesosphere

- Most of the **meteors burn up in this layer** on entering from the space.
- Temperatures drop with increasing altitude to the mesopause.
- **Mesopause is the coldest place on Earth** and has an average temperature around −85 °C.
- Just below the mesopause, the air is so cold that even the very scarce water vapour at this altitude can be sublimated into **polar-mesospheric noctilucent clouds**.
- These are the highest clouds and may be visible to the naked eye during sunset and sunrise.

1.3.4 Thermosphere

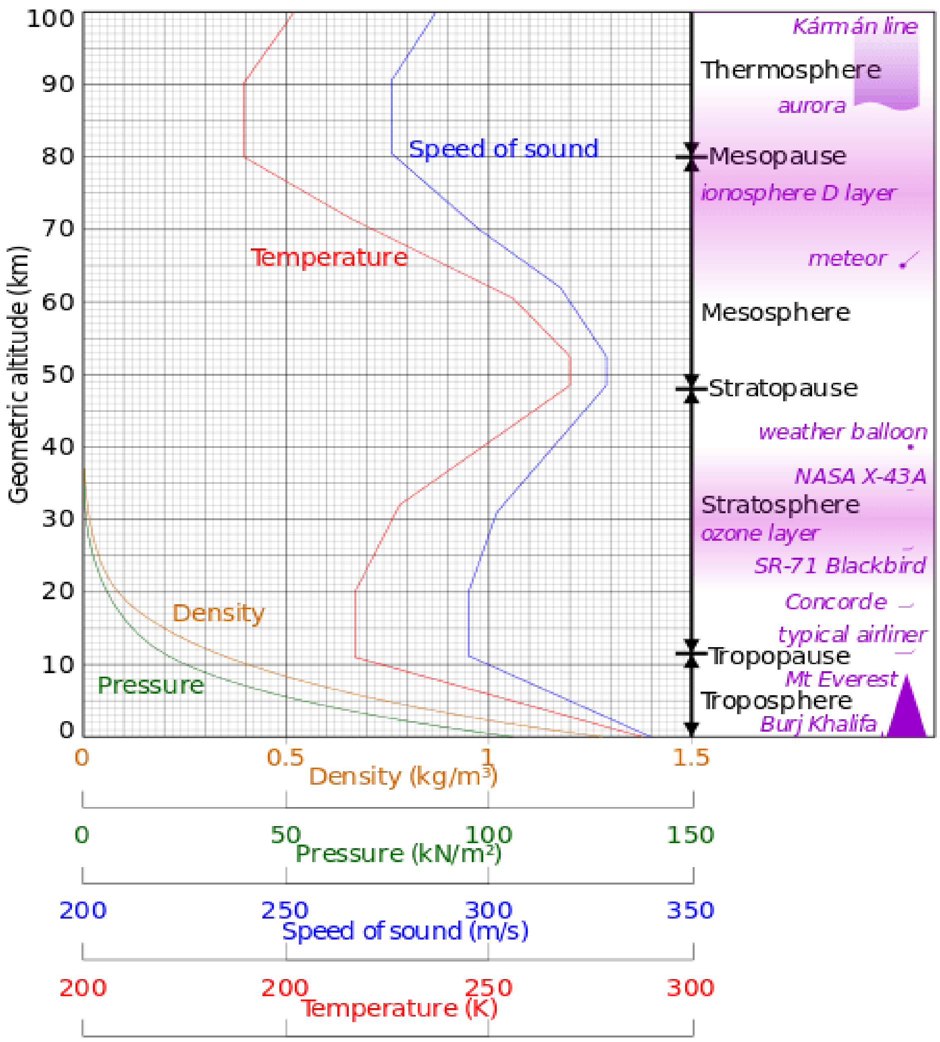
- In thermosphere temperature rises (negative lapse rate) very rapidly with increasing height **because of radiation from the sun**.
- **Ionosphere** is a part of this layer. It extends between 80-400 km.
- Though temperature is high, the atmosphere is **extremely rarefied**– gas molecules are spaced hundreds of kilometres apart. Hence a person or an object in this layer doesn't feel the heat.
- **The International Space Station and satellites orbit in this layer**.
- **Aurora's** are observed in lower parts of this layer.
- The **Kármán line**, located within the thermosphere at an altitude of 100 km, is commonly used to define the boundary between Earth's atmosphere and outer space.
- By international convention, this marks the beginning of space where human travellers are considered astronauts.

The mass of Earth's atmosphere is distributed approximately as follows:

- ✓ ***50% is below 5.6 km or 6 km.***
- ✓ ***90% is below 16 km.***
- ✓ ***99.99997% is below 100 km, the Kármán line.***

Speed of sound follows temperature profile

- *This is because speed of sound is directly proportional to temperature as we move away from earth.*
- *Because in an ideal gas of constant composition the speed of sound depends only on temperature and not on the gas pressure or density.*



Speed of sound follows temperature profile

1.3.5 Exosphere

- This is the uppermost layer of the atmosphere extending beyond the ionosphere above a height of about 800 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.

Atmospheric escape

- Certain light gases like hydrogen are constantly lost into space from exosphere due to atmospheric escape.
- Atmospheric escape of gases (**atmospheric stripping**) happens when gas molecules achieve escape velocity due to **low gravity** or due to energy received from the sun (heat, solar wind).
- Jovian planets retain gases with low molecular masses because of low temperatures and higher gravity.
- Titan, a moon of Saturn, and Triton, a moon of Neptune, possess significant nitrogen-rich atmospheres.
- **Earth's magnetic field** reduces atmospheric escape by protecting the atmosphere from solar wind that would otherwise greatly enhance the escape of hydrogen.

Classification of atmospheric layers based on chemical composition:

They are: i. Homosphere

ii. Heterosphere

The main difference between the homosphere and heterosphere is that the homosphere is the lower part of the atmosphere, up to about sixty miles (100 km), whereas the heterosphere is the upper part of the atmosphere. The homosphere and heterosphere are the two layers of the atmosphere. They have different concentrations of gases depending on the altitude. However, there is no greater variation in the composition of gases in the homosphere. But, there is a greater variation in the composition of gases in the heterosphere. Hence, the gases in the homosphere are in the form of a homogenous mixture while the gases in the heterosphere occur in the form of layers.

(i) Homosphere: The homosphere is the lowest part of the Earth's atmosphere, lying between the Earth's surface and the heterosphere, the upper part. It is the atmosphere, occurring below around 100 km (60 miles). The main feature of the homosphere is the presence of a homogenous mixture of gases as a result of the turbulent mixing or eddy diffusion. Hence, the bulk composition of air throughout the homosphere is uniform.

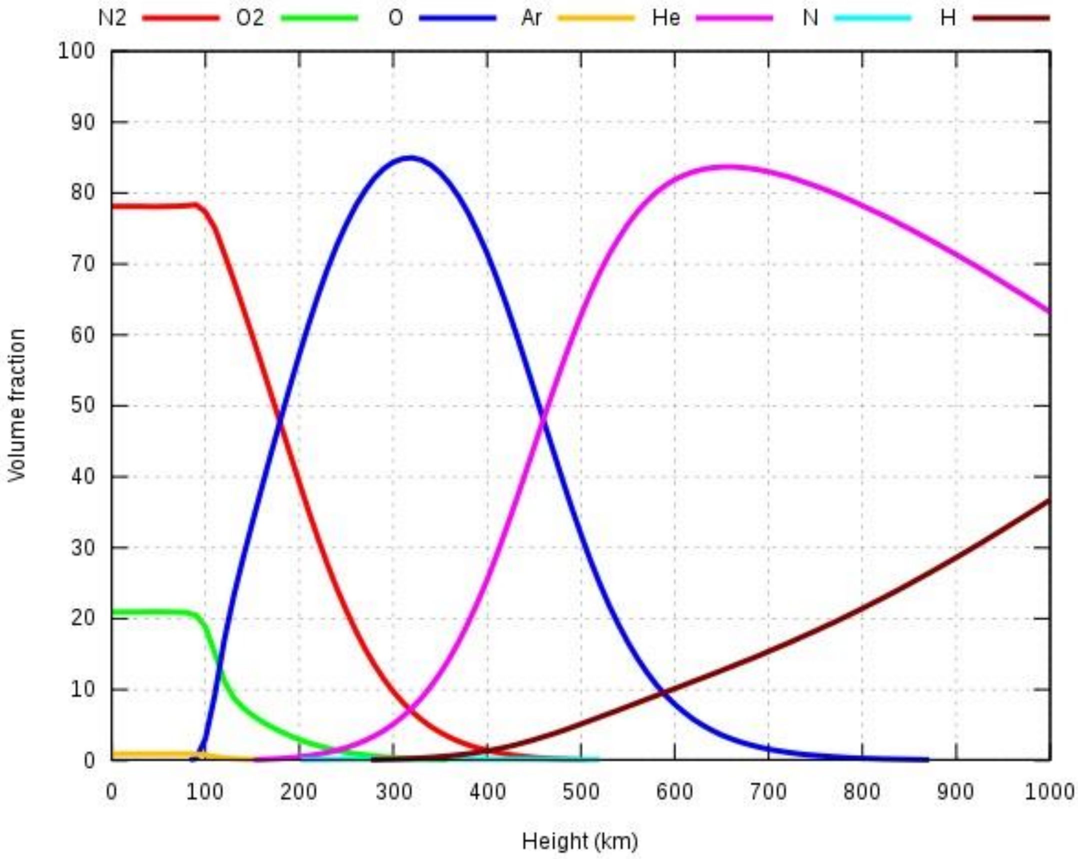


Figure 1: Atmospheric Composition by Height

Moreover, the homosphere contains more than 99% of the mass of the Earth's atmosphere. Also, its composition is usually 78% nitrogen, 21% oxygen, and trace amounts of other molecules, such as argon and carbon dioxide. Although the composition remains the same, the concentration of air decreases with the altitude. Furthermore, the three layers of the homosphere are the troposphere, stratosphere, and mesosphere.

(ii) Heterosphere: Heterosphere is the uppermost layer of the Earth's atmosphere; it begins at about 100 km altitude and extends to the outer reaches of its atmosphere. In heterosphere, the gases separate out into layers by molecular diffusion with the increasing altitude. Also, heavier molecules tend to stay in the lower layers of the heterosphere while the lighter molecules stay in the upper layers. Normally, nitrogen, oxygen, helium, and hydrogen are the major constituents of the heterosphere. However, day and night cycles, solar activity, geomagnetic activity, and seasonal cycles are the other factors affecting the density distribution in the heterosphere in addition to the diffusion.

Moreover, the heterosphere has two layers: thermosphere and exosphere.

HOMOSPHERE
VERSUS
HETEROSPHERE

HOMOSPHERE	HETEROSPHERE
The lower part of the atmosphere, up to about 60 miles, in which there is no great change in its composition	The upper part of the atmosphere, above about 60 miles, in which there is a greater variation in its composition
Occurs up to 60 miles of the atmosphere	Occurs above 60 miles from the earth
Regions: Troposphere, stratosphere, and mesosphere	Regions: Thermosphere and exosphere
There is no greater variation in the composition of gases	There is a greater variation in the composition of gases
Contains a higher proportion of heavier gases such as nitrogen and oxygen	Contains a higher proportion of lighter gases such as hydrogen and helium
The gases occur in the form of the homogenous mixture	The gases occur in the form of layers
The wind highly mixes up the gases	The wind has less influence in mixing gases
The gases show a higher reactivity	The gases show a lower reactivity

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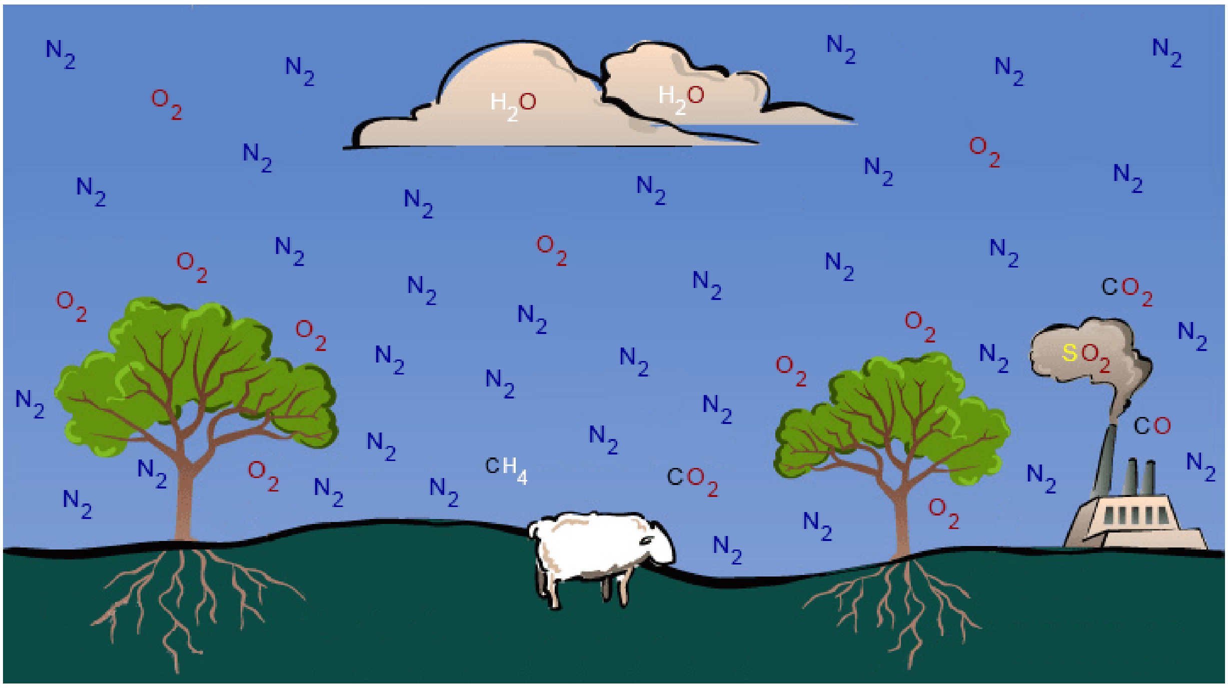


1.4 Importance of Earth's Atmosphere

- Earth is unique among plants as it has life and life on earth would not have been possible if not for the present state of atmosphere.

1.4.1.1 Life-giving gases

- Plants require carbon dioxide to survive while animals and many other organisms need oxygen for their survival.
- Nitrogen is fixed by bacteria and lightning to produce ammonia used in the construction of nucleotides and amino acids.

1.4.1.2 Regulates the entry of solar radiation

- 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.

1.4.1.3 Temperature balance

- 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.

1.4.1.4 Blocks harmful radiation

- The atmosphere helps to protect living organisms from genetic damage by solar ultraviolet radiation, solar wind and cosmic rays.

1.4.1.5 Shields the earth from impact objects

- 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.

1.4.1.6 Weather and climate

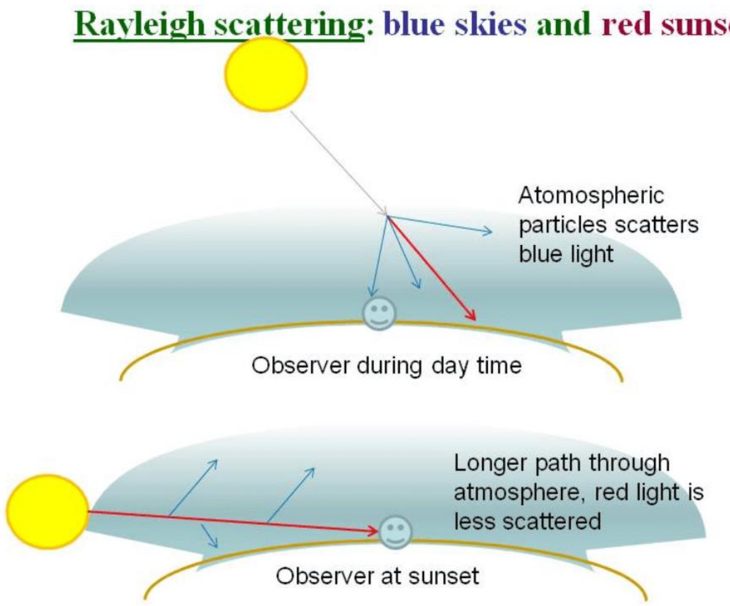
- Weather is another important phenomenon which dictates the direction of many natural and human-made processes like plant growth, agriculture, soil-formation (weathering and erosion), human settlements, etc. Various climatic factors join together to create weather.

1.4.1.7 Water on earth exists in liquid state due to Atmosphere

- Since **liquids cannot exist without pressure**, an atmosphere allows liquid to be present at the surface, resulting in lakes, rivers and oceans.
- Earth and **Titan** are known to have liquids at their surface and terrain on the planet suggests that Mars had liquid on its surface in the past.

1.4.1.8 Scattering of light

- When light passes through Earth's atmosphere, photons interact with it through scattering.
- On an overcast, there is no direct radiation as it has all been scattered by the clouds.
- Due to a phenomenon called **Rayleigh scattering, shorter (blue) wavelengths scatter more easily than longer (red) wavelengths**. This is why the sky looks blue; you are seeing scattered blue light.
- This is also why sunsets are red. Because the Sun is close to the horizon, the Sun's rays pass through more atmosphere than normal to reach your eye. Much of the blue light has been scattered out, leaving the red light in a sunset.



Scattering by atmosphere (Credits)

MULTIPLE CHOICE QUESTIONS (MCQs):

1. The first atmosphere of the earth's surface was consisted of gases primarily hydrogen ( )
   a) Oxygen b) Hydrogen c) Nitrogen d) None of the above
2. Free oxygen did not exist in the atmosphere until about ____________ years ago. ( )
   a) 2.4 billion c) 4.5 billion c) 3.5 billon d) 4.0 billion
3. The modern earth's surface atmosphere contains ___________ % of oxygen. ( )
   a) 0.36 % b) 0.93 % c) 20.95 % d) 78.08 %
4. Ozone plays a crucial role in blocking the harmful ________________ from the sun. ( )
   a) Infrared rays b) Radio waves c) Micro waves d) Ultraviolet rays
5. 90% of moisture content in the atmosphere exists within ____ of the surface of the earth. ( )
   a) 6 Kilometres b) 9 Kilometres c) 12 Kilometres d) 100 Kilometres
6. The blue colour of the sky is due to selective ________ by dust particles. ( )
   a) Reflection b) scattering c) Absorption d) none of the above
7. The soft glowing light from the sky when the sun is below the horizon is called ( )
   a) Dawn c) Dusk c) Aurora d) Twilight
8. Which of the following acts as a boundary between troposphere and stratosphere? ( )
   a) Ozone layer b) Strato pause c) Tropo pause d) None of the above
9. The first appearance of light in the sky before sunrise is called ( )
   a) Dawn c) Dusk c) Twilight d) None of the above

10. Which of the following is commonly used to define the boundary between Earth's atmosphere and outer space? ( )
a) Snow line b) Karman line c) Isotherms d) Contours

11. About 50% mass of Earth's atmosphere is distributed approximately upto _____ altitude. ( )
a) 6 km b) 16 km c) 10 km d) 1600 km

12. Generally, Aurora's are observed in the following atmospheric layer. ( )
a) Troposphere b) Stratosphere c) Mesosphere d) Thermosphere

13. Plants require carbon dioxide to survive while animals and many other organisms need __________ for their survival. ( )
a) Carbon dioxide b) Nitrogen c) hydrogen d) Oxygen

14. The temperature positive lapse rate (NTLR) in troposphere is _________ per kilometre. ( )
a) 3.6 degrees b) 4.5 degrees c) 6.5 degrees d) None of the above

15. Which of the following atmospheric layer contains ideal conditions for aeroplanes flying?( )
a) Troposphere b) Stratosphere c) Mesosphere d) None of the above

16. Ionosphere is a part of thermosphere layer of atmosphere and it extends between ( )
a) 80-400 km b) 8 – 18 km c) 50-85 km d) 85-800 km

17. The artifical satellites orbit in which of the following atmospheric layer. ( )
a) Stratosphere b) Mesosphere c) Thermosphere d) None of the above

18. The upper limit of the stratosphere is called as ( ) a) tropopause b) stratopause c) mesopause d) thermopause

19. Jet streams blow in upper parts of the following atmospheric layer. ( )
a) Troposphere b) Mesosphere c) thermosphere d) Ionosphere

20. Which of the following atmospheric layer supports us for communication? ( )
a) Mesosphere b) Stratosphere c) Ionosphere d) None of the above

Frequently asked Questions (FAQs):

Long:

1. Describe about the composition of earth's atmosphere?
2. How many atmospheric layers are there? Explain them in detail.

Short:

3. Troposphere
4. Ozone layer
5. Heterosphere

Module 02: Insolation: factors effects on distribution

- **INTRODUCTION:**

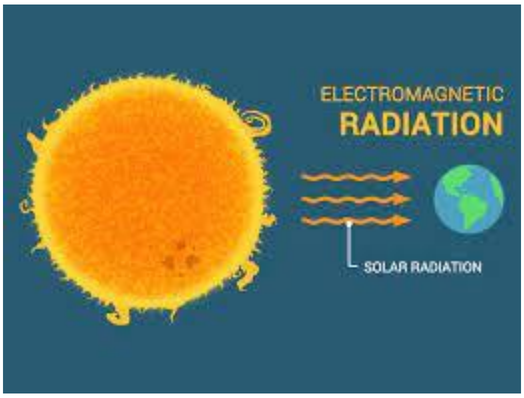
- While moving different parts and places we have been observed about the different temperature as well precipitation conditions of those places. We know that mountain tops are cool to cold whereas the plains are warmer even though they situated on the same latitude on the surface of the earth. You have aware that the temperatures and humidity also vary from region to region because of seasonal changes. The pressure in the air also significantly influenced by variation in temperatures. The variations in the pressure system results in air circulation patterns. Have you ever thought what is the source of heat and energy received on the surface of the earth? Why does earth's surface get warm during the day and cool down during the night? There are several factors which are responsible for these changes or happenings. But we don't know about them. All these variations are seen duo to several factors such as latitude, altitude, sun's position to earth, nature of sky etc. therefore, an attempt is made to discourse about the insolation in general and its factors and distribution in the world in particular.

- The **differential amount of sun's energy received** by various latitudinal zones on earth is the primary reason behind the occurrence of seasonal patterns of weather and climate.
- Thus, understanding the patterns of distribution of temperature in different seasons is important for understanding various climatic features like wind systems, pressure systems, precipitation etc.

- **Sources of Solar Energy**

- The sun is the primary source of almost all the energy on the earth excluding geothermal energy. The sun is a self-luminous body of gases and it is the largest star in solar family. Sun is the centra of solar system. The diameter of the sun is 109 times larger than the earth. The sun's diameter is 13.91 lakhs kilometres. The planet earth and other celestial bodies of solar system receive all the light and heat for their surfaces. Inside the sun, continuous nuclear fusion process take place. As a result of this fusion tremendous amounts of energy is released and emitted from the sun in all the directions.

- **Insolation or Incoming Solar Radiation:**



The upper level atmosphere of earth's surface receives only a part of this radiated energy i.e. Only two billionths or (two units of energy out of 1,00,00,00,000 units of energy radiated by the sun) of the total solar radiation reaches the earth's surface. Nevertheless even this small amount of radiation affects the biological and physical characteristics of earth's surface. The energy is emitted by the sun in the form of electromagnetic energy travels at the speed of light 3,00,00 kms/ second in a spectrum of varying wavelengths. The average distance between the sun and the earth is about 149.6 million kilometres and It takes about 8.3 minutes of time for light waves to reach earth surface.

The energy received by the earth's surface **in the form of short waves** is termed as **Incoming Solar Radiation or Insolation**. The term 'Insolation' is a contraction of "incoming solar radiation". It comprises of a bundle of rays of radiant energy of different wavelengths. The sun emits radiant energy in the form of electromagnetic waves. The wavelength and frequency of these waves which travel with speed of light (3,00,000 km/second) are really staggering. The longer waves largely observed in the atmosphere are called infrared rays. The shorter waves are called the ultraviolet rays representing the other end of the solar spectrum. It is the visible portion of the spectrum lying between the invisible ultraviolet and infrared rays, that most effectively heat the earth. In fact, the rays of the solar spectrum reaching the earth's surface are converted, after absorption by the surface, from short wave to long wave radiant energy. This is what is known as heat. However, there are various factors which cause temporal and spatial variations in the amount of this heat. Various processes of weather and climate are fuelled by the energy gained by the earth's surface and its atmosphere.

- ## Solar constant:

- The amount of radiant energy has been found to be constant. The solar constant is a flux density measuring mean solar electromagnetic radiation per unit area. The solar constant includes all types of solar radiation and not just the visible light. There is little variation in the quantum of solar energy received at the outer margin of our atmosphere, a fact verified by observations made at various places on different occasions. The standard value of solar constant is 1.94 grams square calories per square centimetre per minute (1.94 grams calories/cm2/minute).

FACTORS INFLUENCING INSOLATION

The actual amount of insolation received on the earth's surface is not uniform everywhere. It varies according to the time, place, conditions of atmosphere as well as the seasons. When the tropical regions receive maximum annual insolation, it gradually decreases towards the poles. Insolation is more in summers and less in winters. The following astronomical and geographical factors govern the amount of insolation received at any point on the earth's surface:

i. **Angle of incidence**
ii. **Duration of day**
iii. **Solar constant**
iv. **Distance between the sun and the earth and**
v. **Transparency of the atmosphere.**

i. Angle of incidence

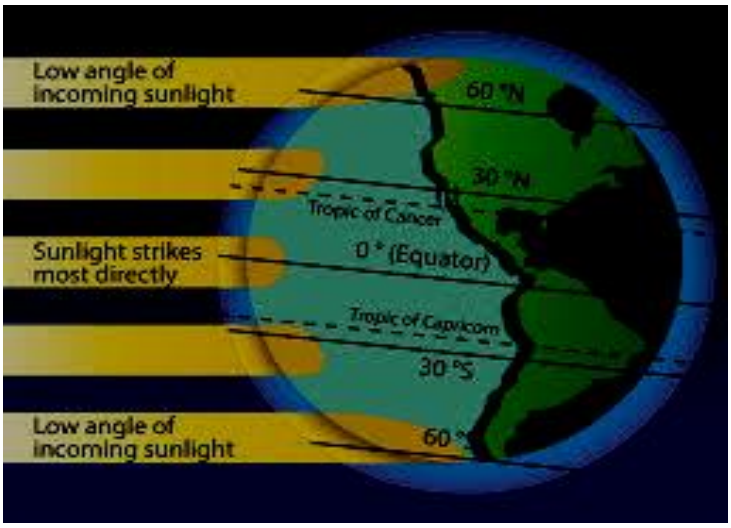
The altitude of the sun, i.e. the angle between its rays and a tangent to the earth's surface at the point of observation, controls the amount of insolation received at the earth's surface (Figure 22.3).
As the elevation angle decreases, the area over which the radiation is distributed increases. The vertical rays of the sun heat the minimum possible area, but on the contrary, the oblique rays are spread over a relatively larger area, so that the amount of area over which the available solar energy has to be distributed in increased and the energy per unit area on the earth's surface is decreased.

In addition, the oblique rays have to traverse a larger distance through the atmosphere before they strike the surface of the earth. The longer their path, the larger the amount of energy lost by various processes of reflection, absorption, and scattering, etc.

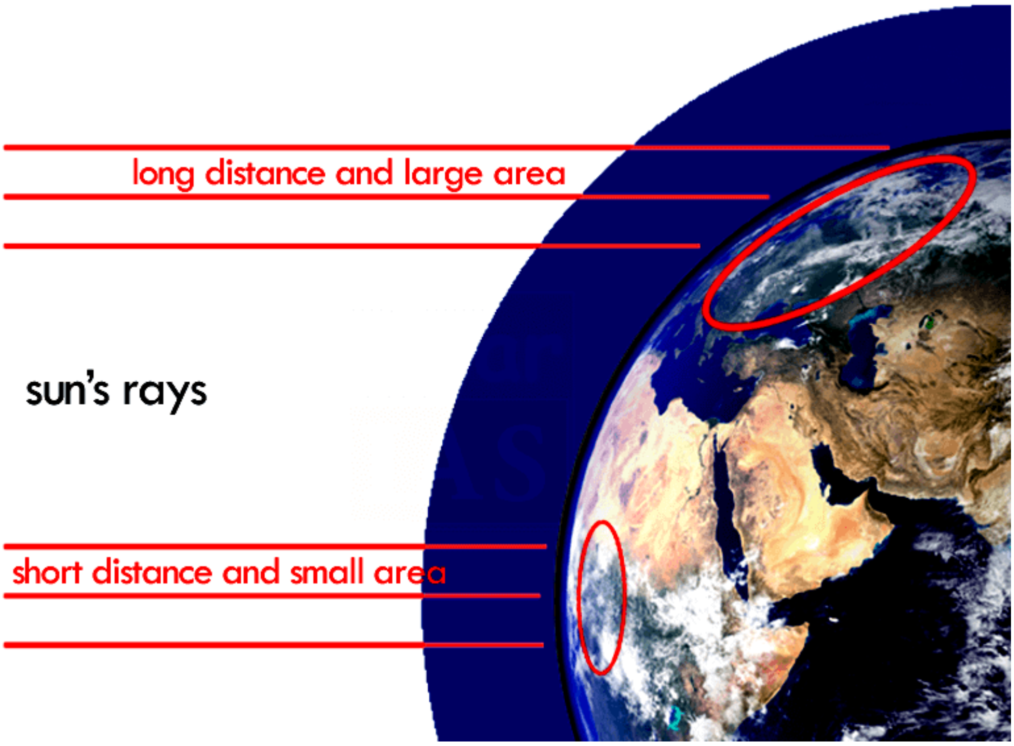
Thus, it is clear that the larger amount of radiant energy is destroyed in case of slanting rays than in vertical rays. Similar effect of the varying angle of sun's rays can be seen in the daily march of the sun across the sky.

At mid-day the intensity of insolation is maximum, but in the morning and evening hours it is reduced because of the slanting rays of the sun. So is the case in winter and at high latitudes, when the-amount of insolation received at the surface of the earth is small.

This is simply the effect of the low angle of incidence. The major factors that determine the sun's altitude or the angle of incidence are the latitude of the place, the time of the day and the season.



- Since the earth is a geoid resembling a sphere, the sun's rays strike the surface at different angles at different places. This depends on the latitude of the place.
- The higher the latitude, the less is the angle they make with the surface of the earth.
- The area covered by the vertical rays is always less than the slant rays. If more area is covered, the energy gets distributed and the net energy received per unit area decreases.
- Moreover, the sun's rays with small angle traverse more of the atmosphere than rays striking at a large angle.



ii. Duration of the day

The duration of sunlight hours determines the length of the day, which also affects the amount of solar radiation received at the surface. Undoubtedly, the longer period of sunshine ensures larger supply of radiation which a particular area of the earth will receive.

Obviously, the latitudes exercise the most dominant control over the duration of sunshine and thereby the length of the day. The latitudinal and monthly variations in the length of days have been shown in Table **(below)**.

The inclination of the earth's axis, its parallelism, the earth's rotation and revolution, all these factors combine together to bring about seasonal changes. It is to be remembered that these astronomical factors not only cause differences in the altitude of the sun, but also differences in the length of day from the equator pole-ward.

At the equator the length of days and nights is 12 hours. On the autumnal and vernal equinoxes that occur on September 21 and March 21 respectively, the mid-day sun is overhead at the equator.

Latitude	Longest day or night	Latitude	Longest day or night
0	12 hours	63.4	20 hours
17	13 hours	66.5	24 hours
31	14 hours	67.4	1 month
41	15 hours	69.8	2 months
49	16 hours	78.2	4 months
58.5	18 hours	90.0	6 months

On these days all over the earth the days and nights are equal. On these two days, the maximum amount of insolation is received at the equator, and the amount goes on decreasing towards the poles.

But from the winter solstice (December 22) onward the length of day increases in the northern hemisphere till the summer solstice (June 21). On the contrary, during this period the length of day in the southern hemisphere decreases and the nights are longer.

From June 21 to December 22 the length of day in the northern hemisphere decreases, and in the southern hemisphere it increases. In other words, at the summer solstice the northern hemisphere has the longest day and the shortest night.

The condition is reversed in the southern hemisphere. On the contrary, at the winter solstice the southern hemisphere has the longest day, and the northern hemisphere has the longest night.

At the respective summer solstice, under cloudless skies, a polar area may receive more radiation per 24 hour-day than other latitudes. It may be pointed out that because of the albedo of ice and snow surfaces the net radiation used for heating is largely reduced.

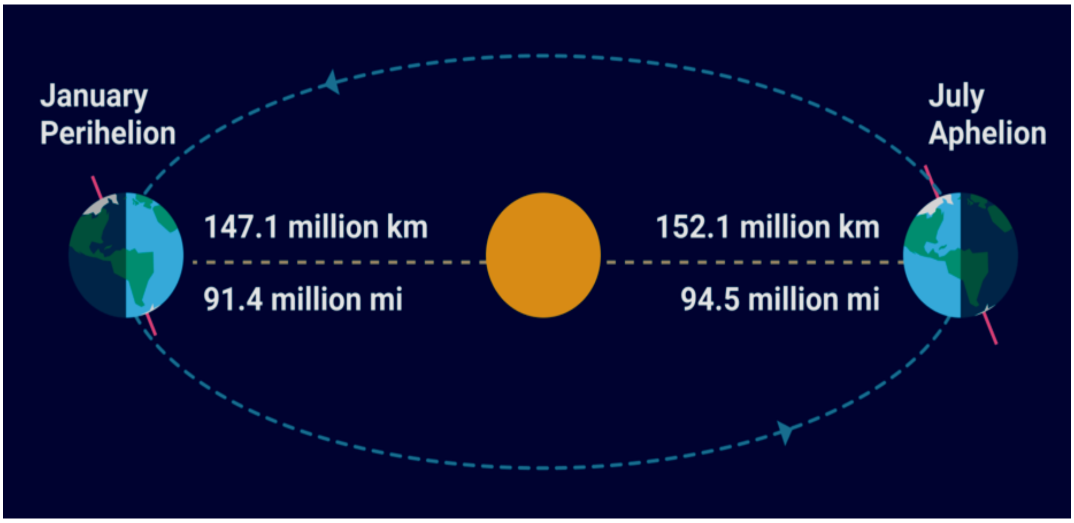
Thus, the longer the period of sunshine and shorter the night, the greater the amount of solar radiation received, all other conditions being equal.

iii. Solar constant

- As the energy emitted by the sun varies, the amount of insolation received at the surface also changes. But the percentage of change in the solar constant is rather negligible. The variations in the solar constant are caused by periodic disturbances and explosions in the solar surface.
- The sun-spot studies that have been carried so far establish that when the sun-spots appear in larger numbers, the intensity of the solar radiation received at the surface is increased. Naturally, therefore, as the number of sunspots decreases, the quantity of radiation received at the earth's surface declines.
- The scientists are of the opinion that the number of sunspots increases or decreases on a regular basis, creating a cycle of 11 years. However, there is little doubt that the magnitude of the effect of the varying amount of the solar constant on the amount of solar radiation received here on earth seems to be too small.

iv. Distance between the sun and the earth

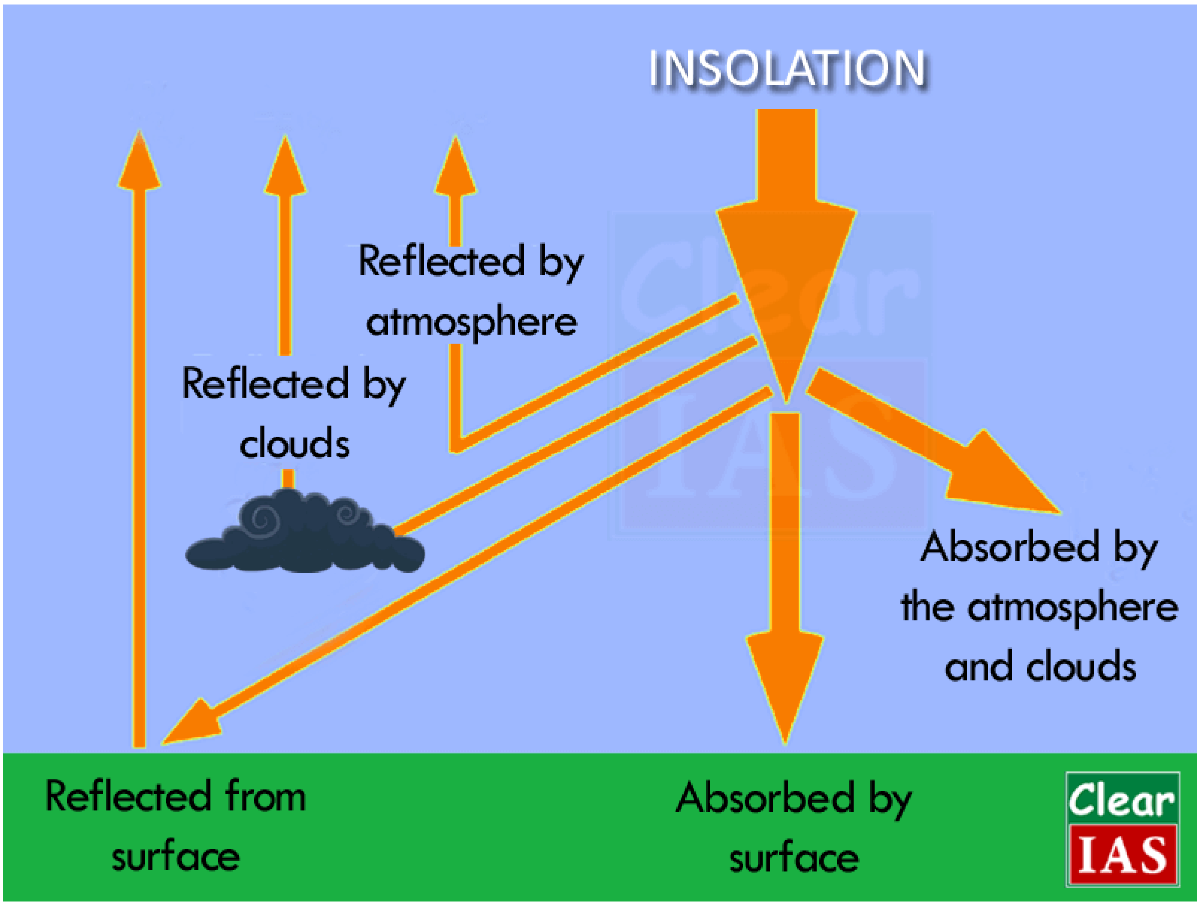
- Since the earth revolves around the sun in an elliptical orbit, the distance varies during the course of a year. The mean distance between the earth and sun is about 149,000,000 kilometers.
- Each year, on about January 3, the earth comes closer to the sun (distance 147 million kilometers). This position is known as perihelion. On about July 4, the earth is a little farther from the sun when the distance becomes about 152 million kilometers. This position is called aphelion.
- Although the amount of incoming solar radiation received at the outer boundary of the atmosphere is a little greater (7 percent) in January than in July, there are other major factors, such as the angle of incidence and the duration of sunshine that more than offset its effect on seasonal temperature variations.
- It may be interesting to note that the earth is relatively closer to the sun during the northern hemisphere winter.



v. The transparency of the atmosphere

- Transparency of the atmosphere is an important control on the amount of insolation which reaches the earth's surface. Reflection from dust, salt, and smoke particles in the air is an important mechanism for returning shortwave solar radiation to space.

- Similarly, reflection from cloud tops also depletes the amount of solar radiation that would otherwise be available to the earth. The effect of certain gases, water vapour, and dust particles on reflection, scattering, and absorption is well-known.
- Obviously, areas with heavy cloudiness and turbid atmosphere will receive lesser amount of radiant energy at the surface. But the transparency of the atmosphere varies with time and place.
- Transparency of the atmosphere is closely related to the latitude. In the higher latitudes the sun's rays are more oblique, so that they have to pass through relatively thicker layers of the atmosphere than at lower latitudes. In winter when the altitude of the sun is relatively lower, there is greater loss of incoming solar radiation than in summer.



Since atmospheric depletion plays a very significant role in the receipt of solar radiation at the earth's surface, a more detailed discussion of this factor follows.

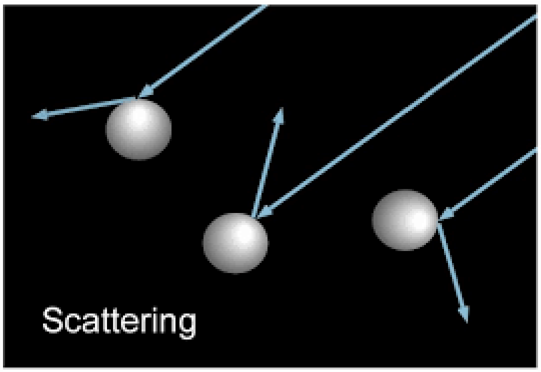
Atmospheric Depletion of Solar Radiation

The loss of solar energy in passing through the atmospheric layers is called the atmospheric deflection. Depicts how solar radiation has to traverse thick and dense layers of the atmosphere in reaching the earth's surface. The longer the path traversed, the greater the amount of radiant energy depleted. Various processes whereby heat energy is lost through the atmosphere are known as scattering, diffusion, absorption, and reflection.

Scattering:

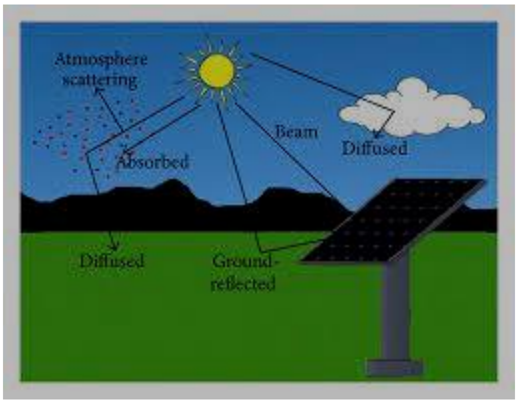
- The atmosphere is composed of molecules of air, water vapour and dust particles. These molecules scatter the shorter ultraviolet waves in different directions. This process, in meteorological parlance, is known as scattering.

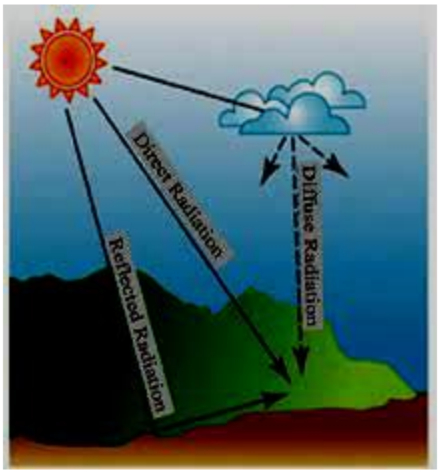
- The solar rays consist of light and heat waves of different wavelengths. When the ultraviolet rays pass through such molecules as have diameters shorter than their wavelengths, the blue and violet colour spectrums get scattered.
- But the red colour spectrum with larger wave-lengths manages to reach the surface of the earth. Thus, when we look at the sky away from the direct rays of the sun, we see more of blue light which was more readily scattered.
- At sunrise and sunset the oblique rays have to pass through the longest path of the atmosphere, hence all the colour spectrums except the red and orange are scattered. It is only the red and the orange colours that reach our eyes. This accounts for the reddish hue of the sky during the twilight hours.



Diffusion:

- When diameter of the particles is larger than the wave-length of the incident beam of light, true scattering does not occur, and the effect of the particles is of the nature of diffuse reflexion or diffusion. It is effective for all wave- lengths.
- Since the process of diffusion is non-selective, component colours of the incident light do not get separated. That is why the light reflected from a cloud, when the sun is behind the observer, is pure white. The sun, for the same reason, appears white when seen through a fog composed of water droplets.
- It is principally due to the diffusion of light in all possible directions by the dust particles present in the air that we have sufficient working light before the sunrise and after the sunset. This diffused light is called the twilight.

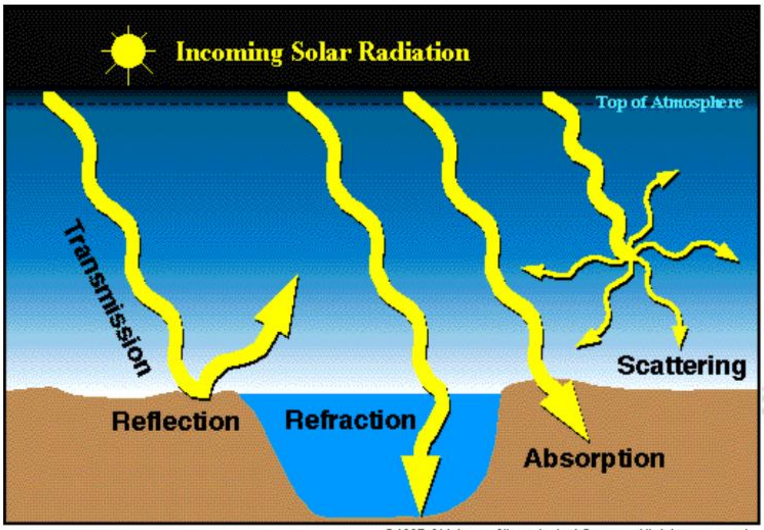




- The astronomical and civil twilights last till the sun has sunk below the horizon 18° and 6° respectively. The twilights are of longer duration in high latitudes than in low latitudes.
- It is of interest to note that it is mainly due to diffuse reflection that there is light in the rooms and under the trees. Thus, solar radiation suffers loss through diffuse reflection by larger particles, such as cloud droplets which occur in greater quantities at low altitudes in the atmosphere.
- There is difference in the effects of small particles and cloud particles that are relatively larger. The molecules or small particles scatter a larger percentage of light of shorter wavelengths causing the direct beam to be richer in red rays, and the scattered light to be richer in blue rays than the incident light.
- On the contrary, the larger particles in a cloud are incapable of producing any change in the relative intensities of the different wave-lengths.
- When a cloud appears reddish in colour, it should not be taken to be the result of a selective scattering effect produced by the cloud particles themselves. It is on account of the loss of blue light by scattering from the beam illuminating the cloud.

Absorption:

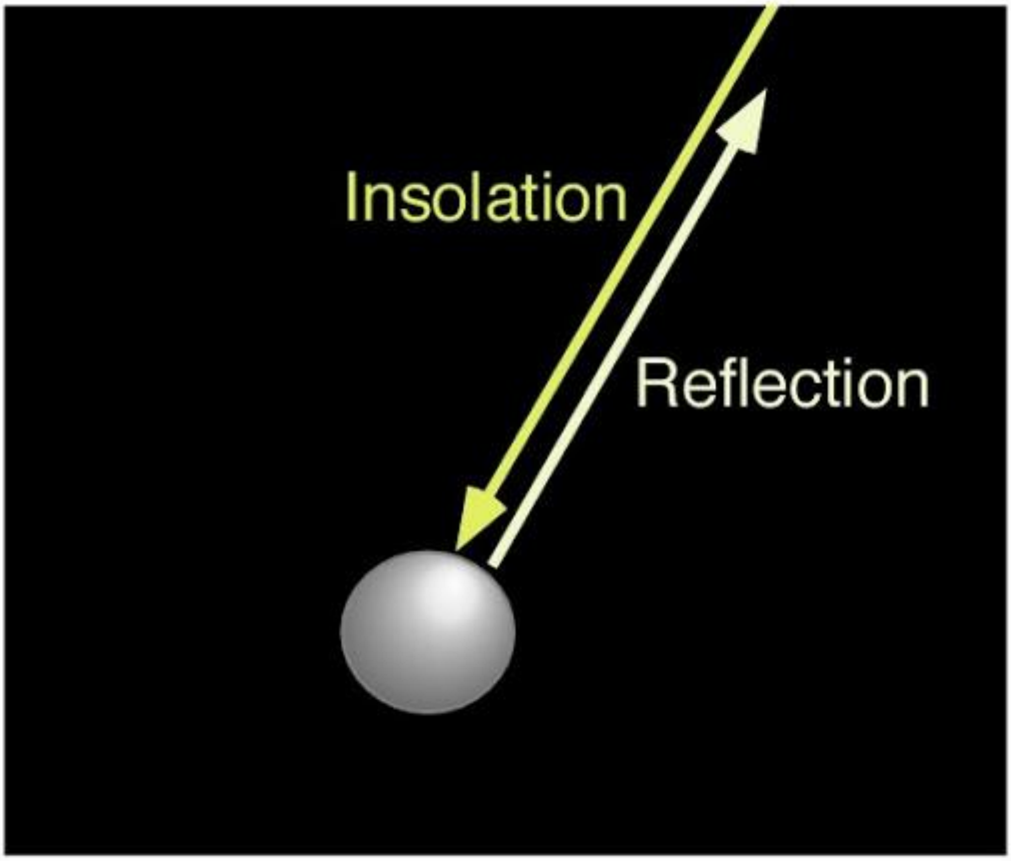
- Absorption has been defined as the process in which the incident radiation is retained by a substance and is irreversibly convered to some other form of energy. There is a certain amount of radiant energy loss by the process of absorption in the atmosphere.
- It may be pointed out that gases do not play very significant role, since they are selective absorbers. Their capacity to absorb solar radiation differs for different wavelengths. When a gas molecule absorbs light waves, this energy is transformed into internal molecular motion which causes a rise in temperature.
- Nitrogen is a very poor absorber of incoming solar radiation. Oxygen and ozone are said to be the good absorbers of solar radiation shorter than 0.29 micrometer. At high altitudes oxygen absorbs most of the ultraviolet rays. In the stratosphere ozone removes ultraviolet radiation of relatively longer wave-lengths.
- The most important and efficient absorber of ultraviolet radiation is water vapour which along with oxygen and ozone absorbs roughly 15 percent of the total solar radiation within the atmosphere.
- In addition, carbon dioxide gas, which is present in the atmosphere in very small quantity up to the great heights, is an efficient absorber of incoming solar radiation that comes in the wave-lengths of about 15 microns.
- In the direct absorption of incoming solar radiation, the water vapour present in the lowermost layer of the atmosphere plays the most significant part. In the electromagnetic spectrums a larger percentage is comprised of the infra-red waves.



- According to Kendrew, about 43 percent of the incoming solar radiation is received through these longer infra-red waves. A larger percentage of these longer waves is directly absorbed by water vapour.
- It may be mentioned that after the gases absorb incoming solar radiation they become heated by the conversion of radiant energy into heat. Thereafter, these absorbing gases start radiating the converted heat as long-wave radiation.
- The cloud drops as well as the dust particles have little contribution to make in the absorption of incoming solar radiation. They are important for the purposes of scattering and diffuse reflection.
- Thus, it is clear that the loss of incoming solar radiation in the atmosphere is in direct proportion to the amount of water vapour present. Since water vapour is mostly transparent to the shorter ultraviolet rays and opaque to the longer infra-red rays, it acts as a screen to long-wave radiation.
- The shorter ultraviolet rays pass through this gas clearly, but the longer waves of the incoming solar radiation are partly absorbed. Similarly, water vapour is an effective absorber of long wave terrestrial radiation.
- In fact, water vapour is the most effective regulator of the surface temperature of the earth. This effect of the atmosphere is known as the greenhouse-effect. In a greenhouse the glass walls or glass roofs allow the short-wave solar radiation to pass through them, where it is absorbed by the ground and converted into heat.
- But the long-wave terrestrial radiation is not allowed to escape the roof and the walls of the greenhouse. Thus, the heat inside the greenhouse is maintained at a certain level.

Reflection:

- A part of the incident radiation falling on any surface is reflected back. It is called the reflection of light. Thus, a certain amount of energy is lost and it does not play any role in heating the atmosphere.
- The reflectivity of a substance, usually expressed as a percentage of the incident radiation reflected, is known as its albedo or reflection coefficient. It differs from place to place as well as from time to time in the same locality.
- It depends upon the amount of cloudiness and atmospheric impurities, the obliquity of the sun's rays, and the nature of the surface. The albedo for the earth as a whole, also known as the planetary albedo, is 35 per cent.



Multiple Choice Questions

1. The energy received by the earth's surface **in the form of short waves** is termed as ( )
   a) Heat b) Albedo c) **Insolation** d) None of the above
2. The standard value of solar constant is _____ square calories per square centimetre per minute ( )
   a) **1.94 grams** b) 2.94 grams c) 10 grams d) None of the above
3. The factors govern the amount of insolation received at any point on the earth's surface ( )
   a) Angle of incidence b) Duration of day c) Solar constant d) **All the above**
4. At the equator the length of days and nights is _______ hours. ( )
   a) 10 hours b) **12 hours** c) 14 hours d) 24 hours
5. On about July 4, the earth is a little farther from the sun when the distance becomes about 152 million kilometers. This position is called ________. ( )
   a) Perihelion b) **Aphelion** c) Dawn d) Dusk
6. The loss of solar energy in passing through the atmospheric layers is called the ( )
   a) **Atmospheric depletion** b) Convection c) Albedo d) None of the above
7. The process in which the incident radiation is retained by a substance and is irreversibly converged to some other form of energy. ( )
   a) **Absorption** b) Scattering c) Diffusion d) None of the above
8. Which of the following gas is a very poor absorber of incoming solar radiation? ( )
   a) Oxygen b) Hydrogen c) **Nitrogen** d) Ozone

9. The Albedo for the earth as a whole, also known as the planetary albedo, is _____ per cent. ( )

a) 66 b) 23 c) 19 d) **35**

10. In the electromagnetic spectrums a larger percentage is comprised of the _______ waves. ( )

a) Visible rays b) **Infra-red** c) UV rays d) None of the above

Long questions:

1. Describe the factors influencing distribution of solar insolation?
2. Discuss about atmospheric depletion of solar radiation?

Short questions:

3. Solar constant
4. Scattering
5. Reflection of light

Module 03: Temperature: Horizontal and vertical distribution

- The **differential amount of sun's energy received** by various latitudinal zones on earth is the primary reason behind the occurrence of seasonal patterns of weather and climate.
- Thus, understanding the patterns of distribution of temperature in different seasons is important for understanding various climatic features like wind systems, pressure systems, precipitation etc.

1.2 Ways of Transfer of Heat Energy

Radiation

- Radiation **doesn't** require a medium for heat transfer.
- Heat is transferred from one body to another **without actual contact or movement in the medium**.
- E.g. Heat transfer from sun to earth through space.

Insolation

- **Insolation** is the amount of sun's energy received in the form of radiation by the earth.
- It is measuredas the amount of solar energy received per square centimetre per minute.
- Earth intercepts less than a billionth of solar radiation.
- Earth receives sun's radiation in the form of **short waves (visible light or wavelengths below visible light – most of it is ultraviolet radiation)** which are electromagnetic.
- The earth absorbs short wave radiation during daytime and reflects the **heat** received into space as **long-wave radiation (mostly infrared radiation which is nothing but heat)** during night.

Conduction

- The heat transfer through conduction happens due to **molecular activity** in a conducting medium. There is no actual movement of the medium itself.
- Generally, denser materials like iron, water are good conductors, and lighter medium like air are bad conductors of heat.

Convection

- Convection is the transfer of heat energy by **actual transfer of matter** or substance from one place to another. E.g. heat transfer by convection cells in a boiling pot of water, atmosphere or oceans.

Heat from the interior

- Some heat from within the earth's interior is transferred to the surface through volcanoes, springs and geysers. But this heat received at the surface is negligible compared to that received from sun.
- However, the heat received from the interior at the ocean bottom is key to the survival of deep ocean life forms that depend on bacteria that grow near the volcanic vents.
- At ocean depths, as sunlight is non-existent, photosynthesis is impossible. The bacteria rely on **chemosynthesis**, a process in which microbes use **chemicals** in the vent fluid to produce energy.

1.3 Factors Affecting Temperature Distribution

- The Angle of Incidence or the Inclination of the Sun's Rays
- Duration of Sunshine
- Transparency of Atmosphere
- **Albedo**
- Land-Sea Differential
- Prevailing Winds
- Ocean Currents
- Altitude
- Aspects of Slope
- Earth's Distance from Sun

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

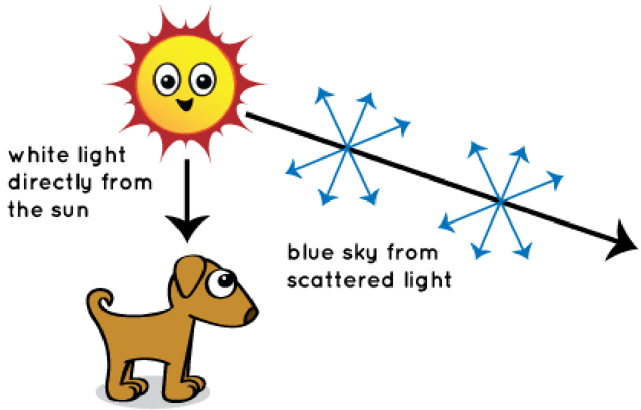
- The area lying close to the equator receives the maximum heat due to near vertical rays of the sun.
- The sun's rays get progressively slanting as one moves away from the equator towards poles.
- As a result, the heat received from the sun decrease as the distance increases from the equator.
- Areas lying close to the poles receive the least of sun's energy as the sun's rays are near horizontal.

Duration of Sunshine

- Heat received depends on day or night; clear sky or overcast, summer or winter etc.
- Earth's atmosphere plays an important role in moderating the temperatures between seasons and between days and nights.

Transparency of Atmosphere

- Aerosols (smoke, sooth, pollen), dust, water vapour, clouds etc. effect transparency.
- **If the wavelength of the radiation is more than the radius of the obstructing particle (such as a gas)**, then **scattering** of radiation takes place.



Scattering of Sun's light (NASA)

- If the wavelength is less than the obstructing particle (such as a dust particle), then **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** (**Greenhouse effect**).
- Most of the light received by earth is **scattered light**.

Albedo

- **Albedo** of a surface is the proportion of sunlight that the surface can reflect back into space.
- Albedo of land is much greater than albedo of oceans and water bodies.
- Snow-covered areas reflect up to 70-90% of insolation.

Land-Sea Differential

- The **specific heat of water is 2.5 times higher than landmass**; therefore water takes longer to get heated up and to cool down.
- Average penetration of sunlight is more in water – up to 20 metres than inland – where it is up to 1 metre or less. 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**.

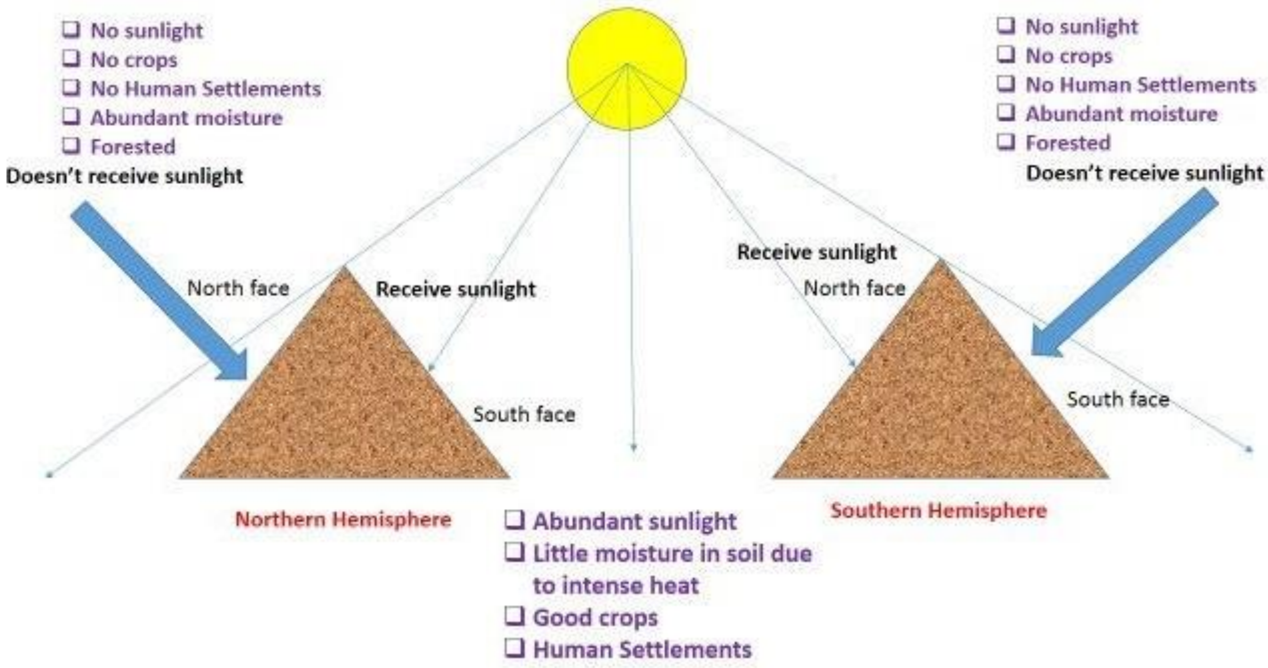
Temperature Anomaly

- 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.**

Prevailing Winds

- Winds transfer heat from one latitude to another. E.g. Poles would have been much colder if it is not for the moderating effect by the atmospheric circulation.
- Winds also help in exchange of heat between land and water bodies. E.g. **Land breeze and sea breeze**.

Aspects of Slope



Insolation along a sloping surface

- The direction and the steepness of the slope 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.
- For example, U.K., considering its latitudinal location, has a relatively moderate climate due to the **warm North Atlantic Drift**.

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°C for every 150-155 metres** of ascent (in troposphere).

Earth's Distance form Sun

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

1.4 The Mean Annual Temperature Distribution

- The horizontal or latitudinal distribution of temperature is shown with the help of a map with isotherms.
- The Isotherms are imaginary lines joining places having equal temperature.
- Effects of altitude are not considered while drawing an isotherm (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 received by all the points located on the same latitude.
- The isotherms are irregular over the northern hemisphere due to an **enhanced land-sea contrast**.
- The thermal equator (ITCZ) generally lies to the north of geographical equator.

Sudden bends at ocean-continent boundaries

- Due to differential heating of land and water and due to ocean currents, temperatures above the oceans and landmasses vary even on the same latitude.

Spacing between isotherms

- Narrow spacing between isotherms indicate high thermal gradient (rapid change in temperature).
- Wide spacing between isotherms indicate low thermal gradient (small or slow change in temperatures).

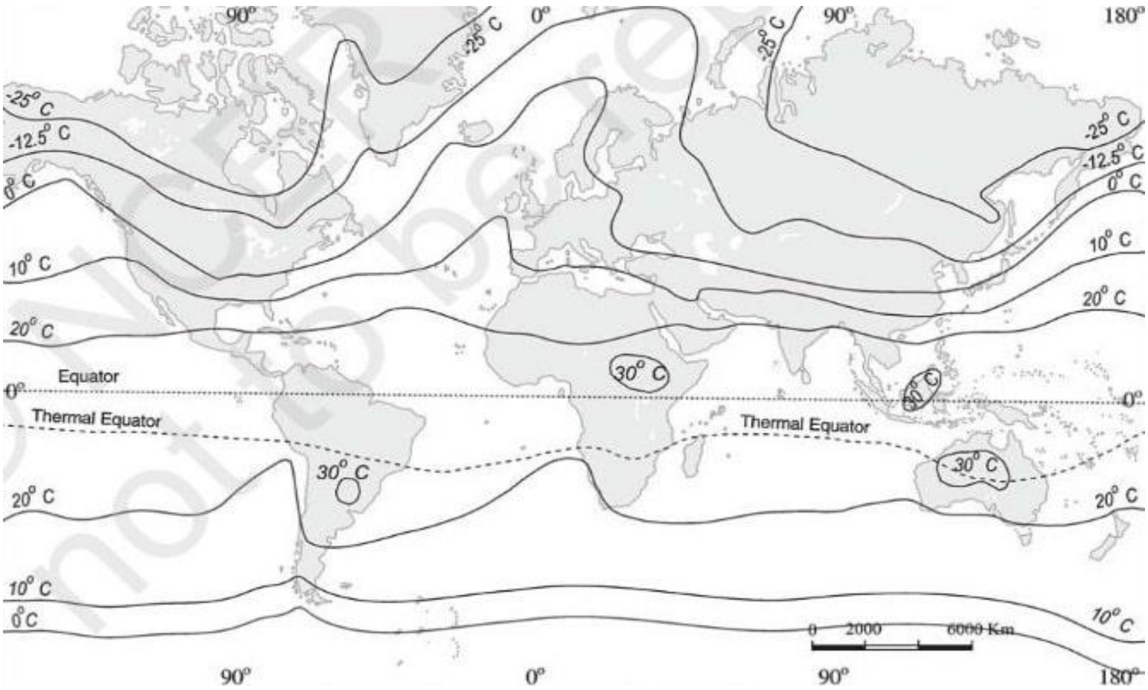
General Temperature Distribution

- The highest temperatures occur over tropics and subtropics.
- The lowest temperatures occur in polar and sub-polar regions and the interiors of large continental subpolar regions due to the effect of **continentality** (far from the moderating effect of the seas).
- Diurnal (daily) and annual range of temperatures are highest in the interiors of continents due to **continentality**.
- Diurnal and annual range of temperatures is least in oceans because of **high specific heat and mixing**.
- The **northern hemisphere is warmer** because of the **predominance of land over water** in the north.
- Low-temperature gradients are observed over tropics (sun is almost overhead the entire year).
- High-temperature gradients are observed 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 because of **warm ocean currents**.
- While passing through an area with warm ocean currents, the isotherms show a **pole ward shift**.
- E.g. North Atlantic Drift and Gulf Stream in Northern Atlantic; Kurishino Current and North Pacific current combined in Northern Pacific.
- Temperature gradients are usually high over the western margins of continents because of **cold ocean currents**.
- Mountains also affect the horizontal distribution of temperature. For example, the Himalayas insulate India from the cold winds of Siberia, the Rockies and the Andes block the oceanic influence from going inwards into North and South America.

Seasonal Temperature Distribution

- 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 **because of the land surface area** which is much larger than in the southern hemisphere.

Seasonal Temperature Distribution– January



(Isotherm map for the month of January)

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

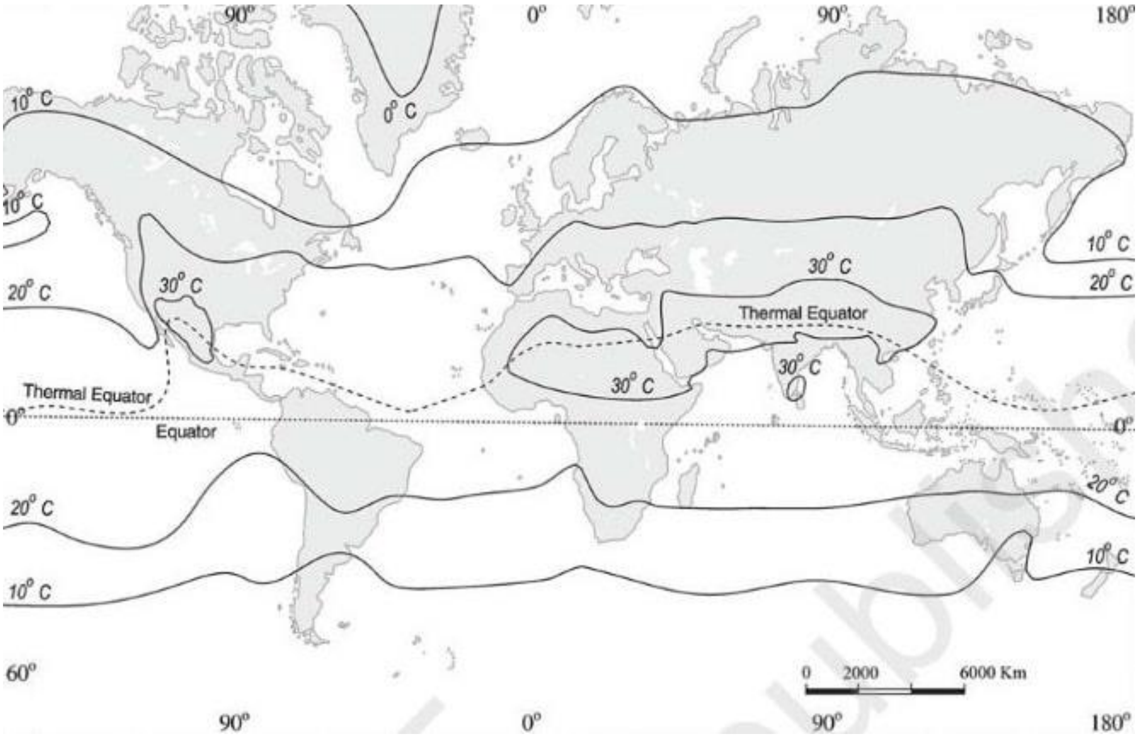
Northern Hemisphere

- The western margins of continents are warmer than their eastern counterparts since the **Westerlies** are able to carry high temperature (from the oceans) into the landmasses.
- The isotherms are closer on the eastern margins as temperature gradient is high because of the **less moderating effect of the oceans** (westerlies flow from west to east).
- The isotherms deviate to the north over the ocean.
- For example, the presence of **warm Gulf Stream and North Atlantic drift** make the Northern Atlantic warmer and the isotherms show a poleward shift indicating that the currents are able to carry high temperatures poleward.
- The isotherms deviate to the south over the continents (**due to continentality**) as the cold polar winds are able to penetrate southwards into the interiors.
- Lowest temperatures are recorded over northern Siberia and Greenland.

Southern Hemisphere

- The effect of the ocean is well pronounced in, and the isotherms exhibit a more regular behaviour.
- The isotherms are more or less parallel to the latitudes, and the variation in temperature is gradual.
- The high-temperature belt runs in the southern hemisphere, somewhere along 30°S latitude (**subtropics are devoid of cloud cover due to anticyclonic circulation at the surface**).
- The thermal equator lies to the south of geographical equator (because the Inter tropical Convergence Zone or ITCZ has shifted southwards with the apparent southward movement of the sun).

Seasonal Temperature Distribution – July

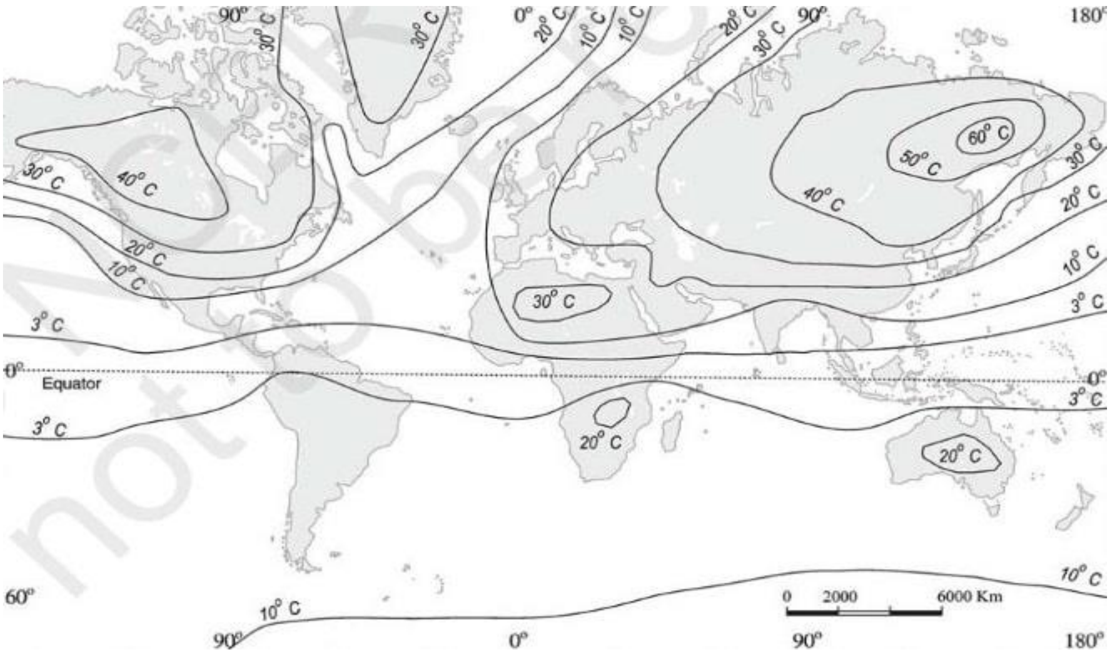


Isotherm map for the month of July

- During July, it is summer in the northern hemisphere and winter in the southern hemisphere.
- The isotherms generally run parallel to the latitudes.
- Thermal equatorlies to the north of the geographical equator.
- 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.

Northern Hemisphere

- The highest annual range of temperature is more than 60° C over the Siberian region (**continentality**).
- The least range of temperature, 3°C, is found between 20° S and 15° N.



The range of temperature between January and July. It is highest in the Siberian region

- 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 equatorward 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 south-eastern USA.
- The temperature gradient is irregular and follows a zig-zag path over the northern hemisphere.

Prelims Practise: 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.

Explanation:

- There is no cloud cover in the subtropics because of the subsiding air and the consequent divergence (anticyclonic circulation) at the surface.
- Subtropical areas have longer day hours in the summer than the equatorial, but the difference is not substantial.
- Moreover, the weather in the equatorial region is turbulent with dense overcast skies and most of the heat is lost in the form of **latent heat of vaporisation**.

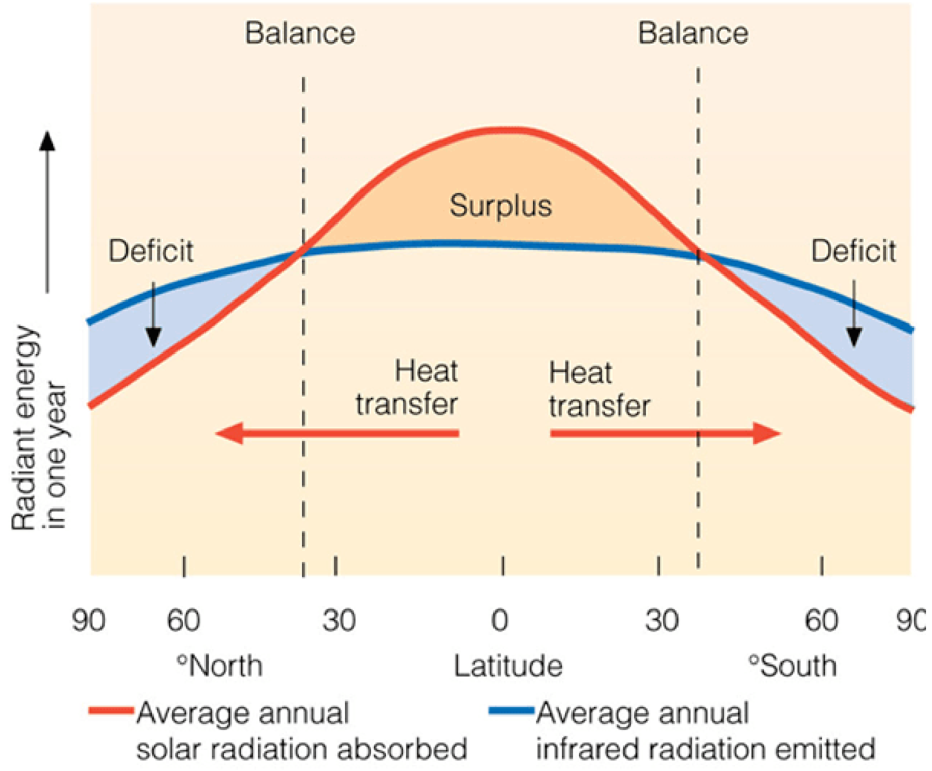
Answer: a) Subtropical areas tend to have less cloud cover than equatorial areas.

Southern Hemisphere

- The gradient becomes regular over the southern hemisphere but shows a slight bend towards the equator at the edges of continents.

1.5 Latitudinal Heat Balance

- 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** (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 progressively cooler. And the planet would have been inhospitable except for few regions near mid-latitudes.
- But this is not the case as the atmosphere and the oceans 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)**, and hence much of the **stormy weather (jet stream and temperate cyclones)** 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.



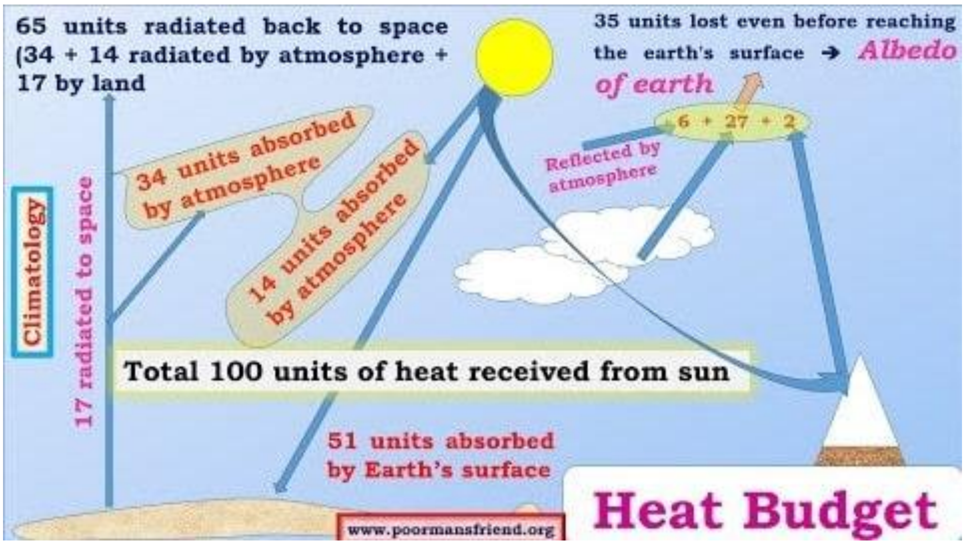
Latitudinal Heat Balance (Credit: NASA)

1.6 Heat Budget

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

Prelims Practise: 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



Explanation:

- 51 units of the incoming shortwave (daytime) radiation is directly absorbed by the earth's surface.

- **35 units are lost even before reaching the surface** due to albedo (2 units), reflection by atmosphere (6 units) and reflection by the clouds (27 units).
- The remaining 14 units of the incoming shortwave (daytime) radiation is absorbed by the atmosphere.
- Hence, the incoming shortwave radiation is responsible for only 14 units out of the **total 48 units absorbed by the atmosphere**.
- The remaining **34 units are received from the outgoing longwave (infrared) terrestrial radiation**.

Answer: d) Long wave terrestrial radiation

Answer in 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? (Hint: **By June 21st Monsoons cover more than half of India**)
4) Why is the annual range of temperature high in the Siberian plains? (Hint: **Continentality**)

Answer in 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.

1.7 Vertical Distribution of Temperature

To understand the vertical distribution of temperature we need to know about latent heat, lapse rate and adiabatic lapse rate

The terms 'Adiabatic Lapse Rate' and 'Latent Heat of Condensation' frequently occur in climatology. Understanding these terms once for all will help immensely in understanding the subsequent topics of climatology.

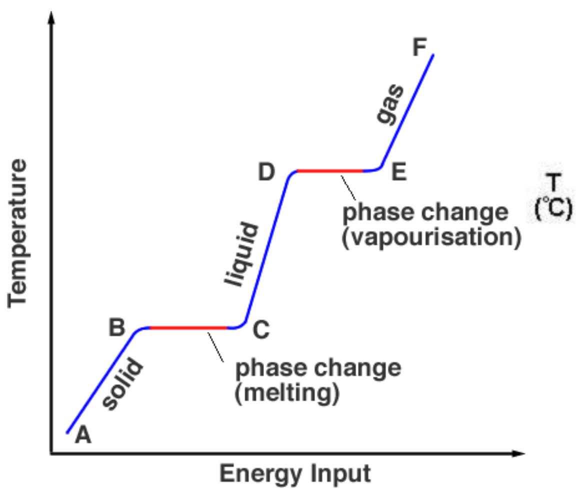
Latent Heat of Condensation

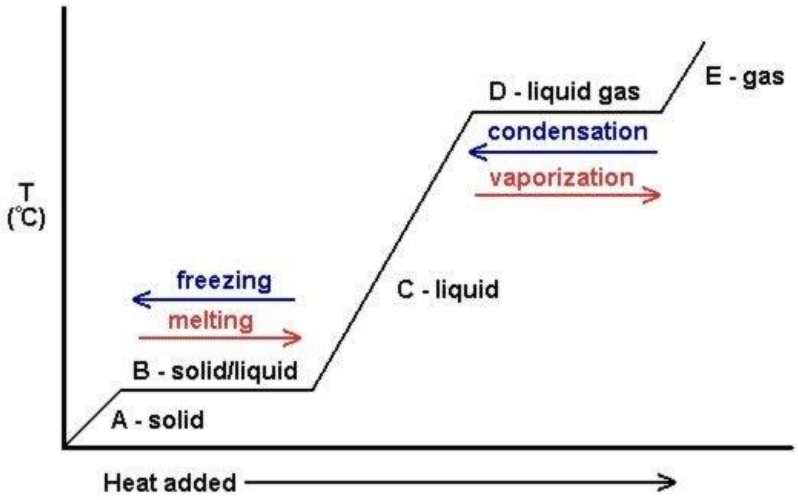
- Adiabatic lapse rate determines the **rate of condensation** in the atmosphere which in turn determines the amount of **latent heat of condensation** released.
- The heat released in the form of **latent heat of condensation** supplies the energy necessary for the formation of towering cumulonimbus thunderstorm cloud and the formation of tropical cyclones.

Latent Heat

- Latent heat is the amount of energy absorbed or released by a substance during a change in its physical state (phase change) that occurs **without changing its temperature**.
- 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 vaporisation** 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





Graph: 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. Then where did the heat supplied go?
- Initially, the heat supplied is used to raise the temperature of the system (A-B and then C-D)
- During phase change, the heat supplied is consumed to turn solid into liquid (B-C: **latent heat of fusion – heat absorbed**) and then liquid into gas (D-E: **latent heat of vaporisation – heat absorbed**).
- Thus, 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 (**latent heat of condensation – heat released**) or liquid into solid (**latent heat of fusion – heat released**), heat is released(this heat is the heat that was used during the phase change process).
- **Thus, latent heat of condensation is the heat released when gases turn into liquid**.

When water vapour in atmosphere condenses into raindrops latent heat of condensation is released.

Water evaporates from the ocean surface by absorbing latent heat of vaporisation.

Lapse Rate

- Lapse rate (**Temperature Lapse** or **Temperature Lapse Rate**) is the rate of change in temperature of the atmosphere with altitude (elevation).
- 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)**.
- Hence, the lapse rate of troposphere below tropopause is positive, the lapse rate of tropopause is zero, and the lapse rate of stratosphere is negative.
- The fall in temperature with altitude is primarily due to the following reason:
  - ✓ Atmosphere is mostly transparent to in the incoming shortwave radiation but actively absorbs the outgoing terrestrial (longwave) radiation.
  - ✓ Greenhouse house gases like CO_2, water vapor, are the primary absorbers of the terrestrial radiation and their concentration is highest at the earth's surface and goes on decreasing with altitude. Hence, temperature falls with altitude.
- The lapse rate of **non-rising air (environmental lapse rate)** is highly variable, being affected by **radiation, convection, condensation and concentration of greenhouse gases**.
- It averages about **6-6.5 °C per kilometre (1°C for every 153-165 metres)** in the lower atmosphere (troposphere).

Adiabatic Lapse Rate (ALR)

- 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 change refers to the **change in temperature with pressure**.
- Adiabatic Lapse rate is governed by **Gas law.**

Adiabatic or adiabatically: *Heat* ***doesn't*** *enter or leave the system. All temperature changes are internal.*

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

Relation between pressure, temperature and volume

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 withstand 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.

But the processes are **non-adiabatic** as there is (will be) heat exchange between the system and the external environment.

Adiabatic Process: Temperature changes in 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 dense (lighter than water) and it rises.
- Similarly, a parcel of air rises when it is less dense than the surrounding environment,and it falls when its density becomes greater than the surrounding environment.
- When an air parcel is subjected to differential heating compared to the surrounding air, it becomes lighter (less dense) or heavier (denser) depending on whether the air parcel is heated or cooled.

A parcel of rising or falling air

- When an air parcel receives more heat than the surrounding air, its temperature increases leading to an increase in volume (increase in volume implies the air parcel is getting less dense).
- 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 volume of the air parcel increases and the hence the temperature of the air parcel falls (gas law).
- This is an **adiabatic** process as there is no heat exchange between the air parcel and the external environment. 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).

- The fall in temperature aids condensation of water vapour. Condensation of water vapour releases **latent heat of condensation** in the process.
- The latent heat of condensation is the **major driving force behind tropical cyclones, convectional rain.**
- Rising of a parcel of air (and associated positive adiabatic lapse rate) is the first step in the formation of thunderstorms, tornadoes and cyclones.

A parcel of falling air

- When an air parcel is in the upper levels, it gets cooled due to lower temperatures (because of lapse Rate).
- Its volume falls, and its density increases. When it becomes denser than the surroundings, it starts to fall.
- This also happens when an air parcel is in contact with cooler surfaces like mountain slopes.
- 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).

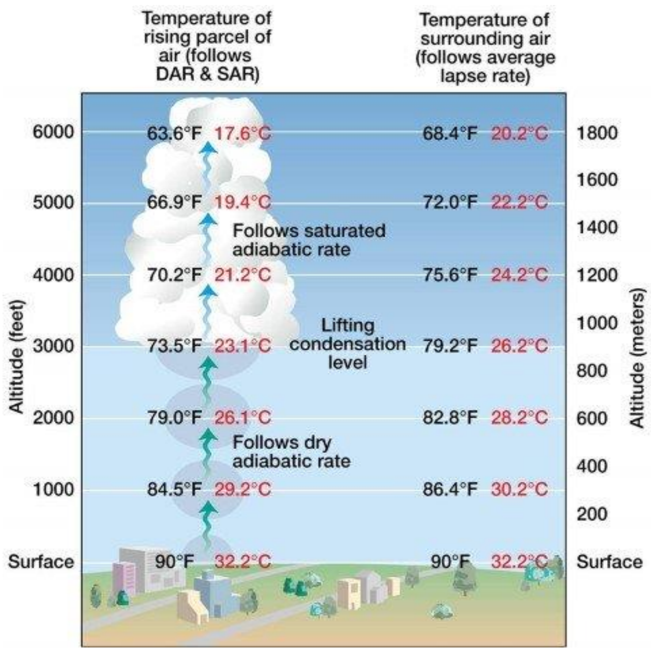
***Lapse Rate*➔** *change in temperature with height.*

***Adiabatic Lapse Rate*➔** *change in temperature of a rising parcel of air without either losing heat to the external environment or gaining heat from the external environment.*

***Rising parcel of air*➔** *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.*

***Falling parcel of air*➔** *On descent through atmosphere, the lower layers are compressed under atmospheric pressure. As a result, the temperature increases.*

***Katabatic Wind*➔** *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 happening adiabatically.*



Adiabatic Lapse Rate and Lapse Rate

Dry Adiabatic Lapse rate (DALR)

- 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) rising under adiabatic conditions.
- Unsaturated air has less than 100% relative humidity.

Saturated air*➔The air cannot hold any more moisture. Its stomach is full.*

***Unsaturated air*➔** *Its stomach is not full. It can accommodate some more moisture.*

- When a rising air parcel has little moisture (below normal), 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 the adiabatic lapse rate of a normal parcel of air.
- The dry adiabatic lapse rate for the Earth's atmosphere is around **9.8°C per kilometre**.
- Dry Adiabatic Lapse rate is mainly associated with **stable conditions(because it has less moisture).**

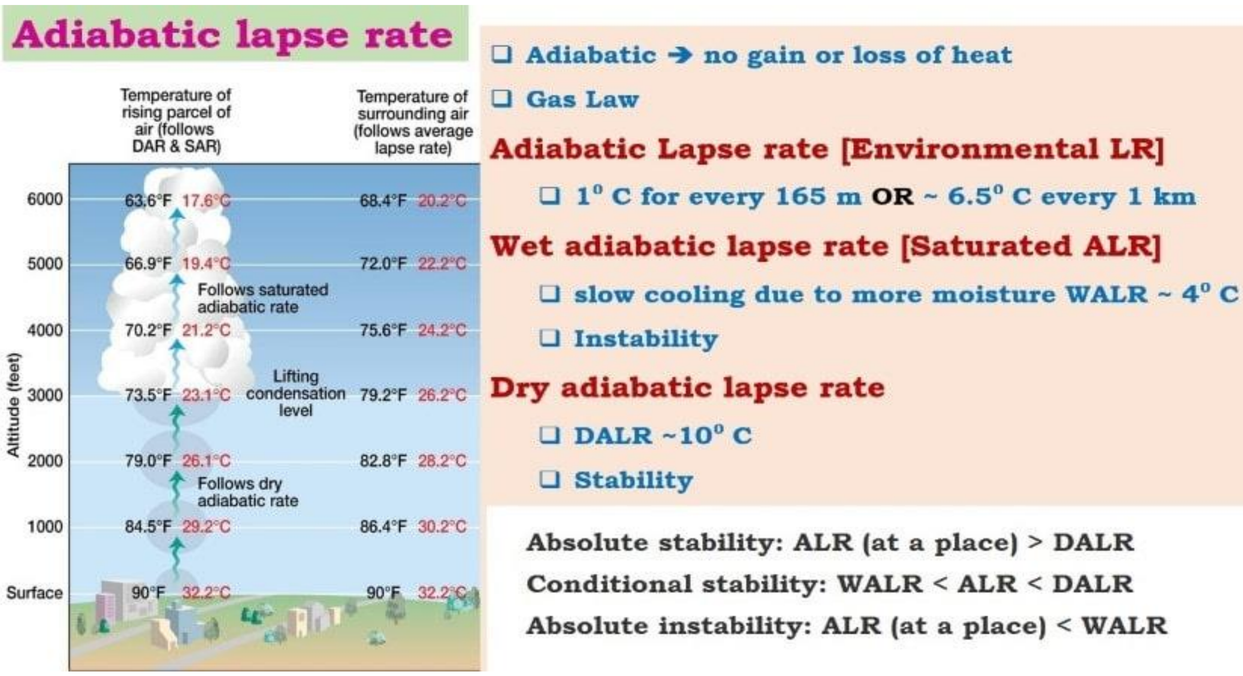
Wet Adiabatic Lapse Rate (WALR)

- 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 (weather forecasting)

- 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



Weather conditions at different adiabatic lapse rates

LR = 6 °C/km

DALR ➔ ALR > 6 °C/km

WALR ➔ ALR < 6 °C/km

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)

Absolute stability: ALR (at a place) > DALR

- The above condition 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 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 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.

Temperature Inversion

UPSC mains 2013: What do you understand by phenomenon of "temperature inversion" in meteorology? How does it affect weather and habitants of the place?

- **Under normal conditions, temperature usually decreases with altitude (positive lapse rate)**.
- Temperature inversion is a reversal of the normal behaviour of temperature in the troposphere, in which a layer of cool air at the surface is overlain by a layer of warmer air (temperature increases with altitude — negative lapse rate).
- In other words, the vertical temperature gets inverted during temperature inversion.

Temperature Inversion

Ideal Conditions for Temperature Inversion

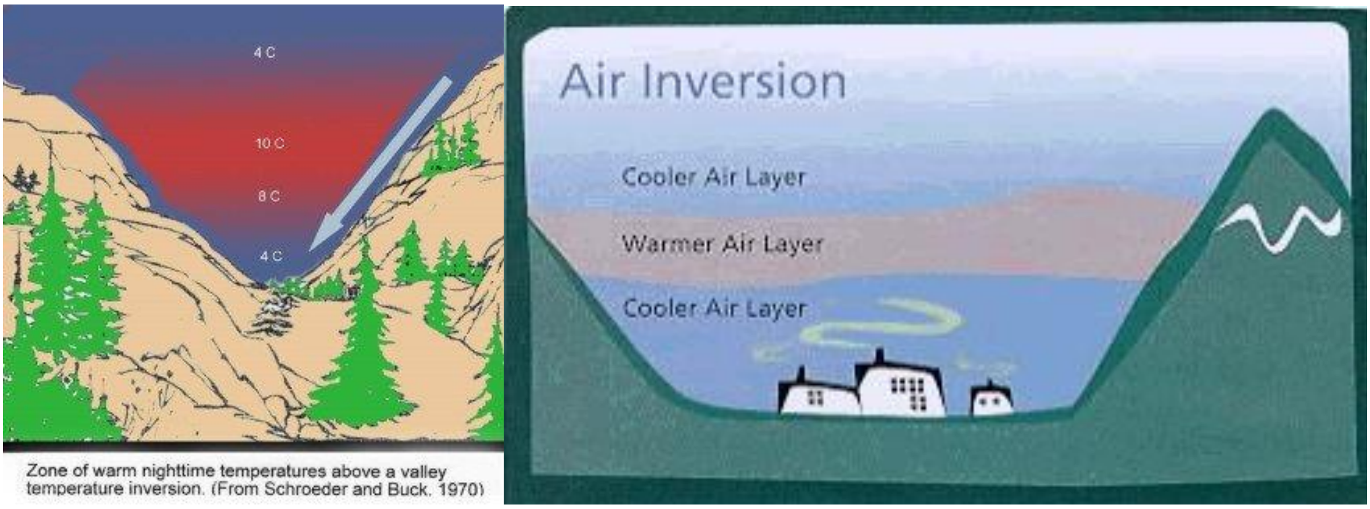
1. **Long nights**, so that the outgoing radiation is greater than the incoming radiation.
2. **Clear skies**, which allow unobstructed escape of radiation.
3. **Calm and stable air**, so that there is no vertical mixing at lower levels.

Types of Temperature Inversion

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

- Sometimes, the temperature **along a sloping surface** increases instead of decreasing with elevation.

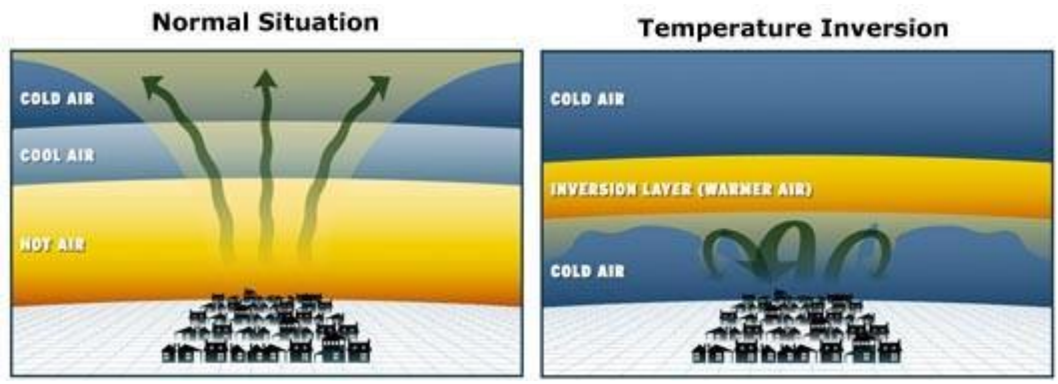
- Here, the top part of the sloping surface radiates heat back to space rapidly and cools the surrounding air making it denser.
- The cold air sinks towards the bottom along the slope and settles as a zone of low temperature at the bottom while the upper layers are relatively warmer.
- This kind of temperature inversion is very strong in the middle and higher latitudes and regions with high mountains or deep valleys.



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

Ground Inversion (Surface Temperature Inversion)

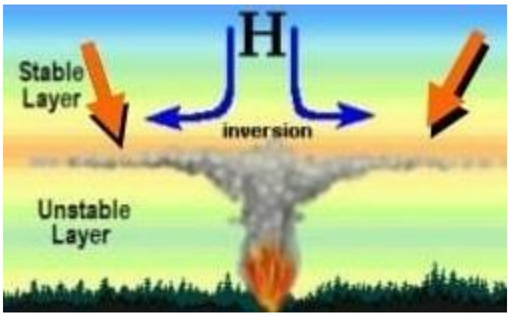
- This type of inversion occurs when air in contact with a colder surface becomes cooler than the overlying atmosphere.
- This occurs most often on clear nights when the ground cools off rapidly by radiation.
- If the temperature of surface air drops below its dew point, **fog** may result.
- This kind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



Ground Inversion (Surface Temperature Inversion)

Subsidence Inversion (Upper Surface Temperature Inversion)

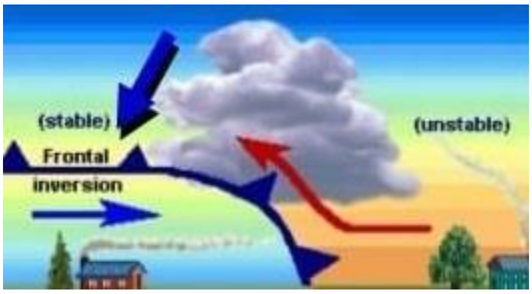
- A subsidence inversion develops when a widespread layer of air descends.
- As it descends, the ambient atmospheric pressure increases and the layer is compressed and heated.
- If the air mass sinks low enough, it forms a warm intermediate layer which is at a higher temperature compare to the layers below, producing a temperature inversion.
- Subsidence inversions are common over areas located under large **high-pressure centres**.
- Such conditions occur in the northern continents in winter and over the subtropical oceans.
- This temperature inversion is also called upper surface temperature inversion because it takes place in the upper parts of the atmosphere.



Subsidence Inversion (Upper Surface Temperature Inversion)

Frontal Inversion (Advectional type of Temperature Inversion)

- A frontal inversion occurs when a cold air mass undercuts a warm air mass and lifts it aloft.
- This kind of inversion has considerable slope, whereas other inversions are nearly horizontal.
- Also, humidity may be high, and clouds may be present immediately above it.
- This type of inversion is **unstable** and is **destroyed as the weather changes**.



Frontal Inversion (Advectional type of Temperature Inversion)

Effects of Temperature Inversion

- **Convection is inhibited**: An inversion acts as a cap on the upward movement of air from the layers below.
- Convection is limited to levels below the inversion, and the rainfall is below normal.
- In regions where a pronounced low-level inversion is present, **convective clouds cannot grow high enough** to produce rain.
- **Pollution is exacerbated**: diffusion of dust, smoke, and other pollutants is limited due to stable conditions.
- 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. Fog lowers visibility affecting vegetation and human settlements.
- Inversions also affect diurnal variations in temperature. Diurnal variations tend to be very **small**.

Effect on intermontane valley regions

- The temperature of the air at the valley bottom can go below freezing whereas the air at higher altitude remains comparatively warm.
- The trees along the lower slopes are bitten by frost, whereas those at higher levels are free from it.
- 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.
- Air pollutants such as dust particles and smoke do not disperse in the valley bottoms.

Module 04: Pressure Systems

4.1 Atmospheric pressure

- 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 at sea level is **1034 gm per square centimetre**.
- Atmosphere (atm) is an internationally recognised unit for measuring atmospheric pressure at a place.
- The units used by meteorologists are **millibars (mb)** and **Pascal (Pa)**.
- One millibar is equal to the force of one gram on a square centimetre.
- A pressure of 1000 millibars is equal to the weight of 1.053 kilograms per square centimetre.
- The normal pressure at sea level is taken to be about 1013.25 millibars (equal to the weight of a column of mercury 75 cm high).

1 atm = 1013.25 millibars (mb) = 101325 pascals (Pa) = 101.325 kilopascals (kPa)

- Atmospheric pressure varies from place to place due to differences in topography, sun's insolation and related weather and climatic factors.

4.2 Atmospheric pressure cells

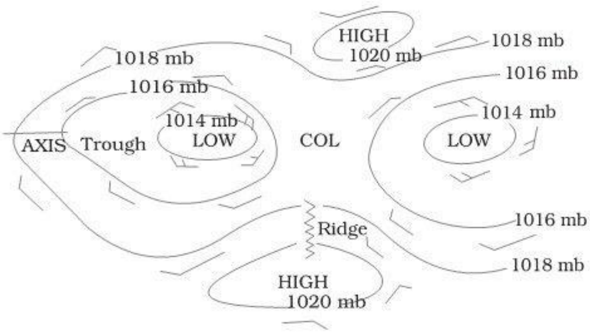
- When heated, the volume of a parcel of air increases (air expands) and hence the pressure within the air parcel falls creating a **low-pressure cell** (low-pressure centre).
- When cooled, the volume of the air parcel decreases (air is compressed) and hence the pressure within the air parcel increases creating a **high-pressure cell** (high-pressure centre).
- A combination of atmospheric pressure cells give rise to distinct pressure systems within the atmosphere.
- 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.

4.3 Isobars

- **Isobars** are lines connecting places having equal pressure.
- The spacing of isobars expresses the rate 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.

4.3.1 Closed Isobars or Closed Pressure centres

- Low-pressure system (low-pressure cell) is enclosed by one or more isobars with the lowest pressure in the centre.
- High-pressure system (high-pressure cell) is also enclosed by one or more isobars with the highest pressure in the centre.



Closed Isobars

4.4 Vertical Variation of Pressure

- In the lower atmosphere, the pressure decreases rapidly with height.
- The decrease in pressure with altitude, however, is not constant because of the factors that control air density (temperature and amount of water vapour) are highly variable.
- 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.
- In general, the atmospheric pressure decreases on an average at the rate of about 34 millibars every 300 metres of height.
- The vertical pressure gradient force is much larger than that of the horizontal pressure gradient. However, it is generally balanced by a nearly equal but opposite **gravitational force**. Hence, we do not experience strong upward winds.

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

- At the height of Mt. Everest, the air pressure is about two-thirds less than what it is at the sea level.

4.5 Factors affecting Wind Movement

Wind: horizontal movement of air

Currents: vertical movement of air.

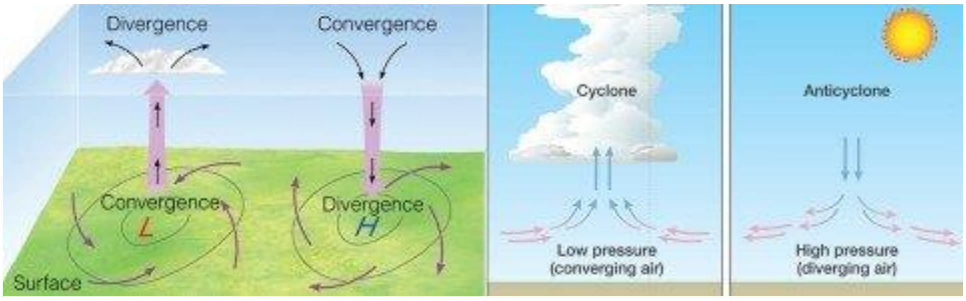
- The factors that affect wind movement are **pressure gradient force, buoyant force, friction, Coriolis force, gravitational force and centripetal acceleration**.

4.5.1 Pressure Gradient Force

- The pressure gradient (difference in pressure) between atmospheric pressure cells and the surroundings causes the movement of air from relatively high-pressure centres to relatively low-pressure centres.
- This movement (motion) of air is called as wind. Greater the pressure difference, greater is the wind speed.
- Small differences in pressure are highly significant in terms of the wind direction and velocity.
- The pressure gradient is strong where the isobars are close to each other and is weak where the isobars are apart.
- The wind direction follows the direction of pressure gradient, i.e. **perpendicular to the isobars.**

4.5.2 Buoyant force

- The atmospheric pressure cells also determine whether the air sinks or rises at a place.
- The surrounding atmosphere exerts buoyant force on low-pressure cells and hence the air within a low-pressure cell rises.
- On the other hand, the air within a high-pressure cell sinks as it is denser than the surrounding atmosphere.
- Rising air is associated with convergence and unstable weather (cyclonic conditions) whereas the sinking (subsiding) air is associated with divergence and stable conditions (anticyclonic conditions).
- A rising pressure indicates increasing stability, while a falling pressure indicates the weather becoming more unstable.
- The converging wind movement around a low is called **cyclonic circulation**.
- Around a high, the wind diverges, and the movement is called **anti-cyclonic circulation**.
- The wind circulation at the earth's surface is associated with an exactly opposite wind circulation above in the upper troposphere.
- Apart from convergence, convection currents, orographic uplift and uplift along fronts cause the rising of air, which is essential for the formation of clouds and precipitation.



Divergence and Convergence. Cyclonic and Anticyclonic conditions

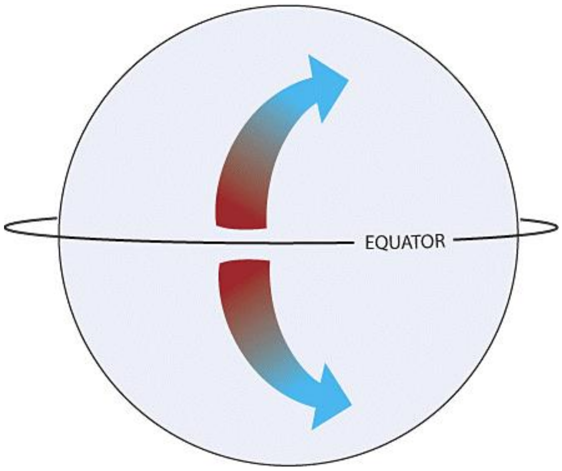
Pressure System	Pressure Condition	Pattern of Wind Direction	
		Northern Hemisphere	**Southern Hemisphere**
Cyclone	Low	Anticlockwise	Clockwise
Anticyclone	High	Clockwise	Anticlockwise

4.5.3 Frictional Force

- The irregularities of the earth's surface resist the wind movement in the form of friction.
- The influence of friction generally extends up to an elevation of 1-3 km.
- Over the sea surface, the friction is minimal.
- At the surface, due to high friction, the wind direction makes high angles with isobars.

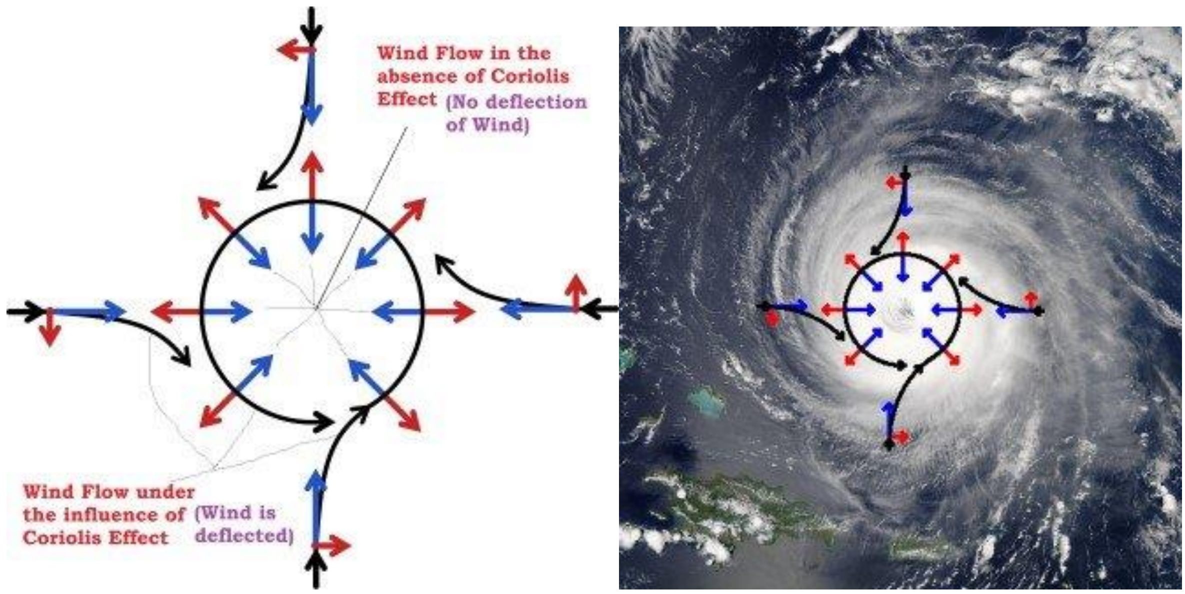
4.5.4 Coriolis force

- 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.



Farrell's Law: winds in the northern hemisphere get deflected to the right

- 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 (Farrell's Law)**.
- This deflection force does not seem to exist until the air is set in motion and increases with **wind velocity**and an **increase in latitude**.



Cyclones in the northern hemisphere rotate anti-clockwise due to Coriolis force

4.5.4.1 Coriolis effect

- The Coriolis effect is the **apparent deflection of objects** (such as aeroplanes, wind, missiles, sniper bullets and ocean currents) moving in a straight path **relative** to the earth's surface.

4.5.4.2 Causes of the Coriolis Effect

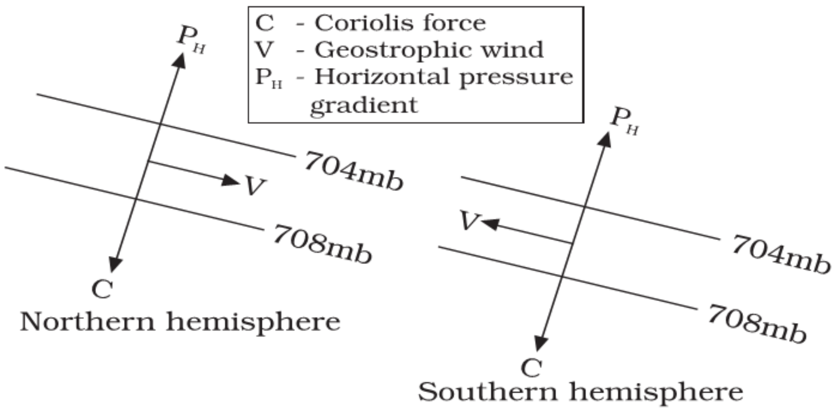
- As the earth spins in a counter-clockwise direction on its axis any object flying over a long distance appears to be deflected.
- This occurs because as something moves freely above the earth's surface, the earth is moving east under the object at a faster speed.
- As the object moves away for the equator the speed of the earth's rotation decreases and Coriolis effect (deflection) 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.

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. But such rotation is result of shape and orientation of the container. Coriolis effect is negligible to cause any deflection at such minor distances.

- The Coriolis effect is related to the motion of the object, the motion of the Earth, and the latitude.
- For this reason, the magnitude (Coriolis force) of the effect is given by $2\nu\omega \sin \phi$, in which ν is the velocity of the object, ω is the angular velocity of the Earth, and ϕ is the latitude.
- At the equator, $\phi = 0°$ and at the poles, $\phi = 90°$. Thus, the **Coriolis force is zero at the equator but increases with latitude, reaching a maximum at the poles**.

4.5.4.3 Geostrophic Wind

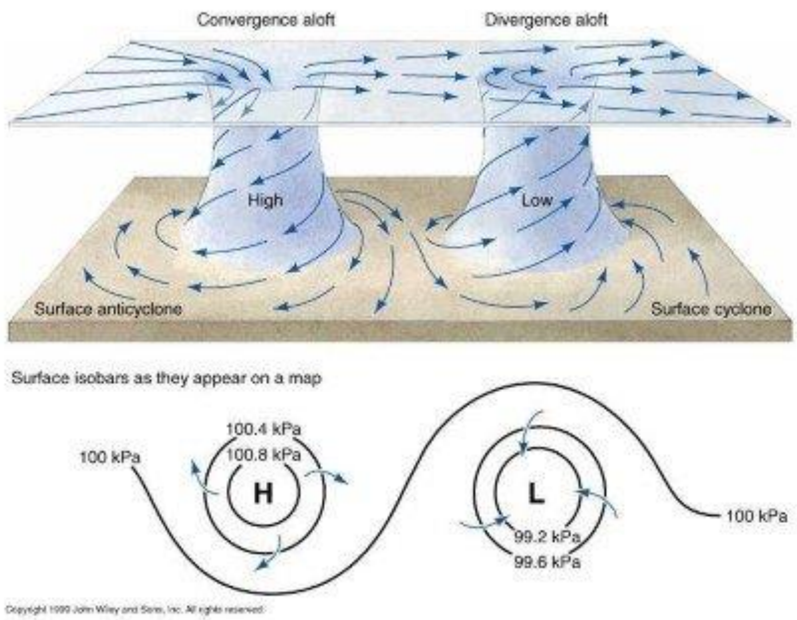
- The Coriolis force acting on a body increases with increase in its velocity.
- The winds in the upper atmosphere, 2-3 km above the surface, are free from frictional effect of the surface and are controlled by the pressure gradient and the Coriolis force.
- When isobars are straight,and when there is no friction, the **pressure gradient force is balanced by the Coriolis force,and the resultant wind blows parallel to the isobar**(deflection of the wind is maximum).
- This wind is known as the **geostrophic wind.**



Geostrophic wind vector parallel to the isobars

4.5.5 Centripetal Acceleration

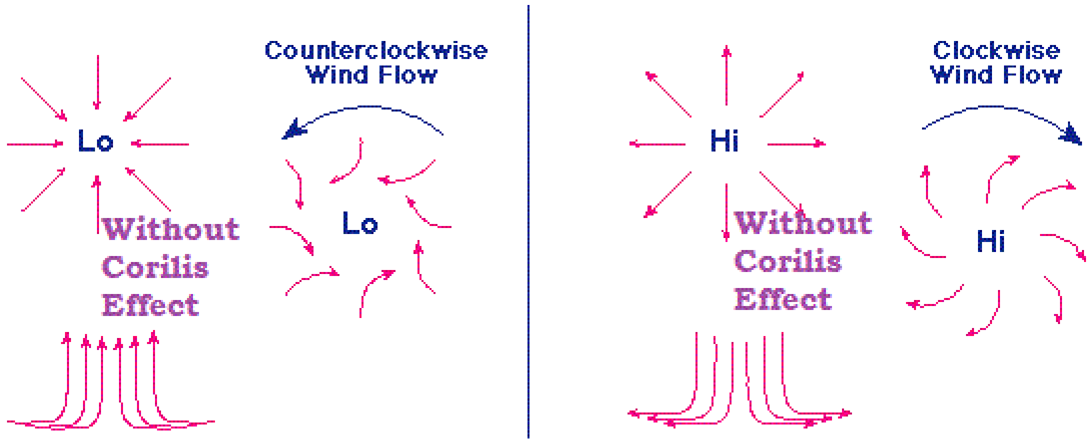
- It acts only on air that is flowing around centres of circulation.
- Centripetal acceleration creates a force directed at right angles to the wind movement and inwards towards the centres of rotation.
- This force produces a circular pattern of flow (vortex) around centres of high and low pressure.



Centripetal acceleration produces a circular flow

4.5.5.1 Why are there no tropical cyclones at the equator?

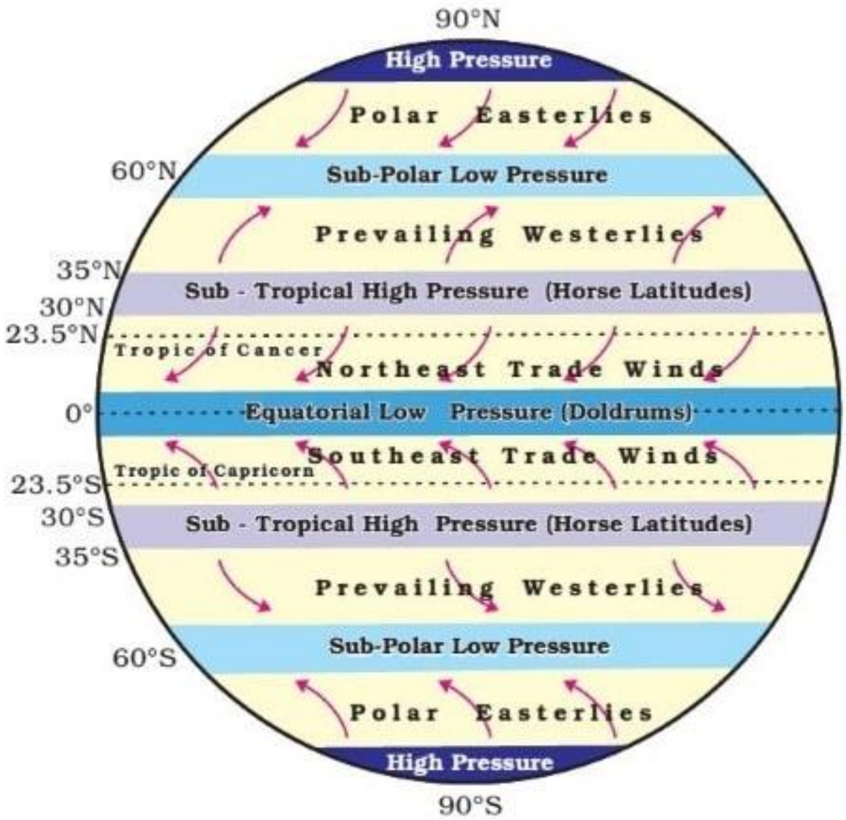
- The low pressure close to the equator gets filled instead of getting intensified,i.e., there is **no spiralling of air due to zero Coriolis effect**. The winds directly get uplifted vertically to form thunderstorms.



Vertical movement of air with and without Coriolis effect

4.6 Horizontal Distribution of Pressure

- Horizontal distribution of pressure is studied by drawing isobars at constant levels by eliminating the effect of altitude on pressure.
- There are seven distinctly identifiable zones of horizontal pressure systems or **pressure belts**.
  1. ***equatorial low,***
  2. ***the sub-tropical highs*** (along 30° N and 30° S),
  3. ***the sub-polar lows*** (along 60° N and 60° S), and
  4. ***the polar highs.***
- Except the equatorial low, all others form matching pairs in the northern and southern hemispheres.



Major Pressure Belts and Wind Systems

- The 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.

4.6.1 Equatorial Low-Pressure Belt or 'Doldrums'

- Th equatorial low-pressure belt lies between **10°N and 10°S latitudes**.
- The position of the belt varies with the apparent movement of the Sun.
- Its width may vary seasonally between 5°N and 5°S and 20°N and 20°S.
- This belt happens to be the **zone of convergence of trade winds (Intertropical Convergence Zone or ITCZ)** from two hemispheres from sub-tropical high-pressure belts.
- This belt is also called the **doldrums**, because of the **extremely calm air movements**.

Zone of convergence of trade winds - ITCZ

4.6.1.1 Formation

- As this region lies along the equator, it receives highest amount of insolation.
- Due to intense heating, the air gets heated up creating a low-pressure region (**thermally formed**).

4.6.1.2 Climate

- The air at the margins of the low-pressure region rises (convection) giving rise to clouds and turbulent weather along the margins.
- **Only vertical currents are found,** and the **surface winds** are almost absent since winds rise near the margin itself.
- Hence the region within the belt is characterised by **extremely low pressure** yet **calm weather conditions**.
- As the larger part of the low-pressure belt passes along the oceans, the winds obtain huge amount of moisture.
- Vertical winds carrying moisture from **cumulonimbus thunderstorm clouds**(convectional rainfall).
- The rising air loses all its moisture by the time it reaches the upper parts of the troposphere.
- Inspite of high temperatures and moisture, **cyclones are not formed 5°N and 5°Sof the equator because of negligible Coriolis force**.

4.6.2 Sub-Tropical High-Pressure Belt or Horse Latitudes

- The sub-tropical highs extend from near the tropics to about **35°N and S.**

4.6.2.1 Formation

- After complete loss of moisture, the air moving away from the equatorial low-pressure belt and the subtropical low-pressure belt in the upper troposphere is dry and cold.
- The **blocking effect of air at upper levels** because of the **Coriolis force forces the cold, dry air to** subside at 30°N and S.

- So, the high pressure (**dynamically formed**) along this belt is due to **subsidence of air coming from the equatorial region and the subpolar region**.

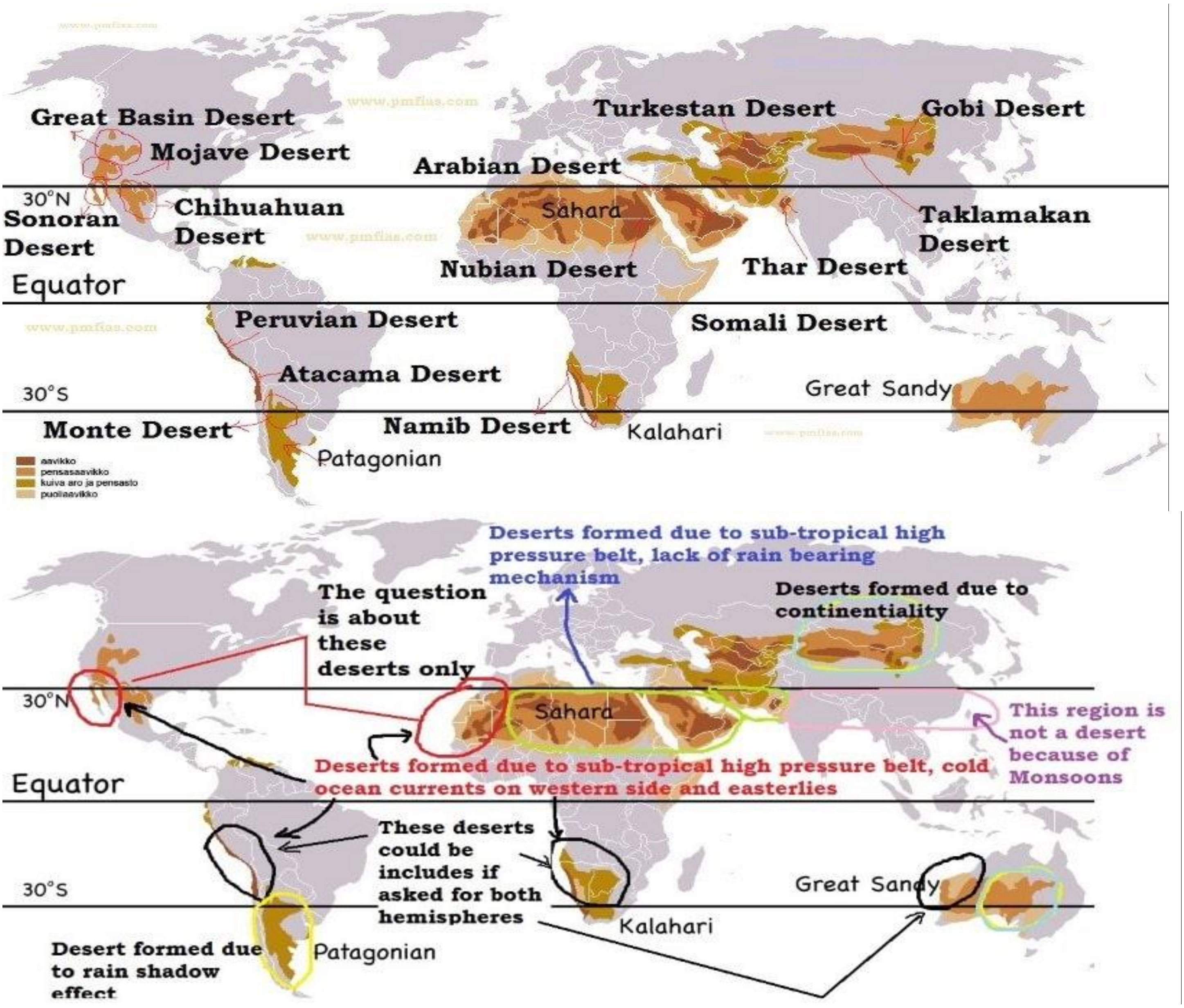
4.6.2.2 Climate

- The **subsiding air is warm (heated due to increases in ambient pressure) and dry, therefore, most of the deserts are present along this belt, in both hemispheres**.
- A calm condition **(anti-cyclonic)** 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**.

4.6.2.3 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.

4.6.2.4 Mains 2013: Major hot deserts in northern hemisphere are located between 20-30 degree north and on the western side of the continents. Why?



Major Deserts of the World

4.6.2.4.1.1 Why between 20 – 30 degree?

- The subsiding air is warm and dry; therefore, most of the deserts are present along this belt, in both hemispheres.

4.6.2.4.1.2 Why on western side of the continents?

- We will get answer for this while studying ocean currents.

4.6.3 Sub-Polar Low-Pressure Belt

- The subpolar low-pressure belts are located between **45°N** and the **Arctic circle (66.5° N) and 45°S and the Antarctic circles (66.5° S) respectively.**
- Owning to low temperatures the subpolar low-pressure belts are not very well pronounced year long.

4.6.3.1 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 (coming from the subtropical high-pressure regions) and polar easterlies (coming from the polar regions)**.
- Subpolar low-pressure belts are mainly encountered above **oceans.**

4.6.3.2 Seasonal behaviour

- During winter, because of a high contrast between land and sea, this belt is broken into two distinct low centres – 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.
- The belt in the southern hemisphere is not as well differentiated.

4.6.3.3 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.

4.6.4 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.

4.6.4.1 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.

4.6.5 Factors Controlling Pressure Systems

4.6.5.1 Thermal Factors

- When air is heated, it leads to low pressure, and when it is cooled, it leads to high pressure.

- Formation of **equatorial low and polar highs** are examples of thermal lows and thermal highs.

4.6.5.2 Dynamic Factors

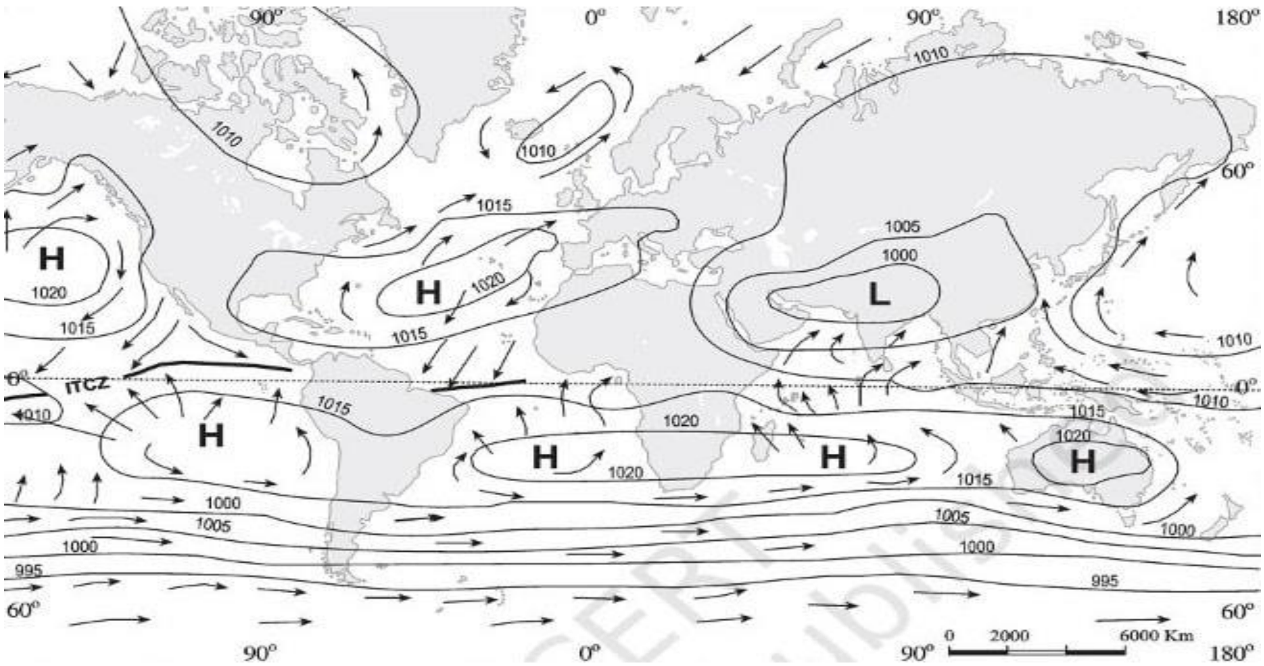
- Apart from variations of temperature, the formation of pressure belts may be explained by dynamic factors arising out of **pressure gradient forces, apparent movement of sun and rotation of the earth (Coriolis force).**

4.6.5.2.1.1 Example

- The **rate of deflection of wind increases with distance from the equator (Coriolis force).**
- The defection is higher in the upper troposphere due to less friction.
- As a result, by the time the poleward directed winds in the upper troposphere reach 25° latitude, they are deflected into a nearly west-to-east flow.
- Similarly, equatorward directed winds in the upper troposphere are deflected into a nearly east-to-west flow.
- This 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.

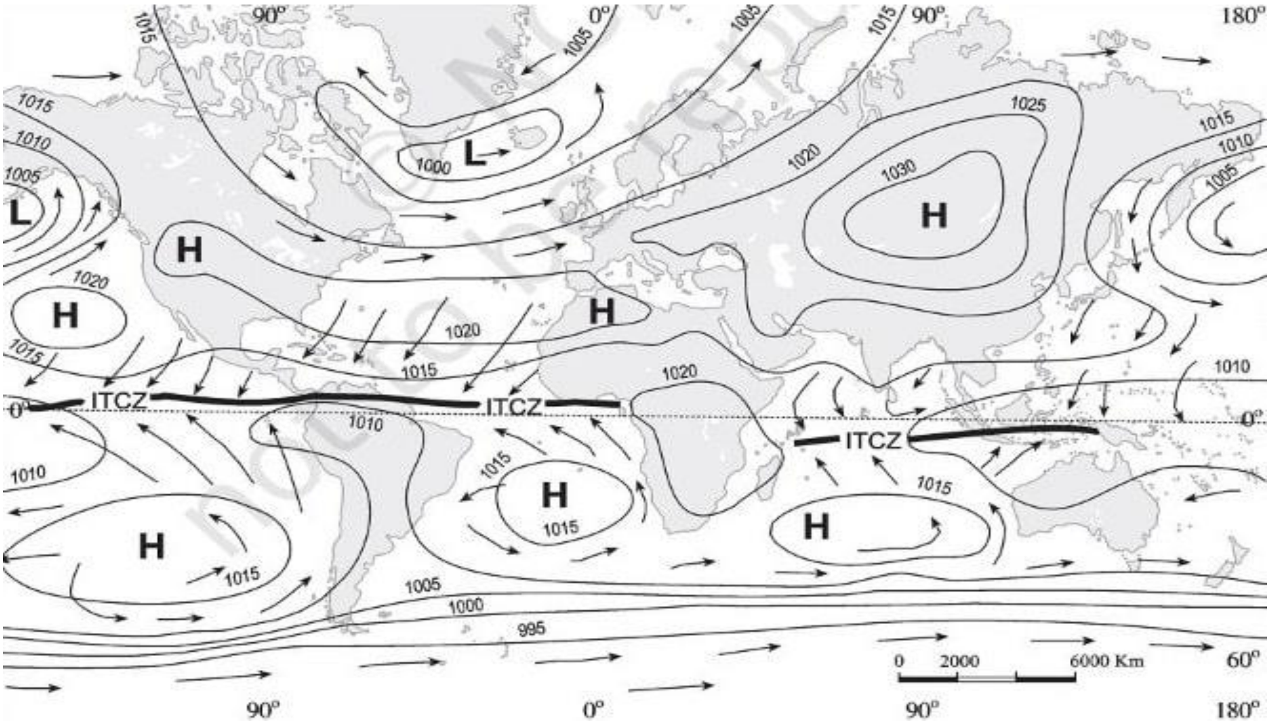
4.6.6 Pressure belts in July

- 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.



Pressure belts in July

4.6.7 Pressure belts in January

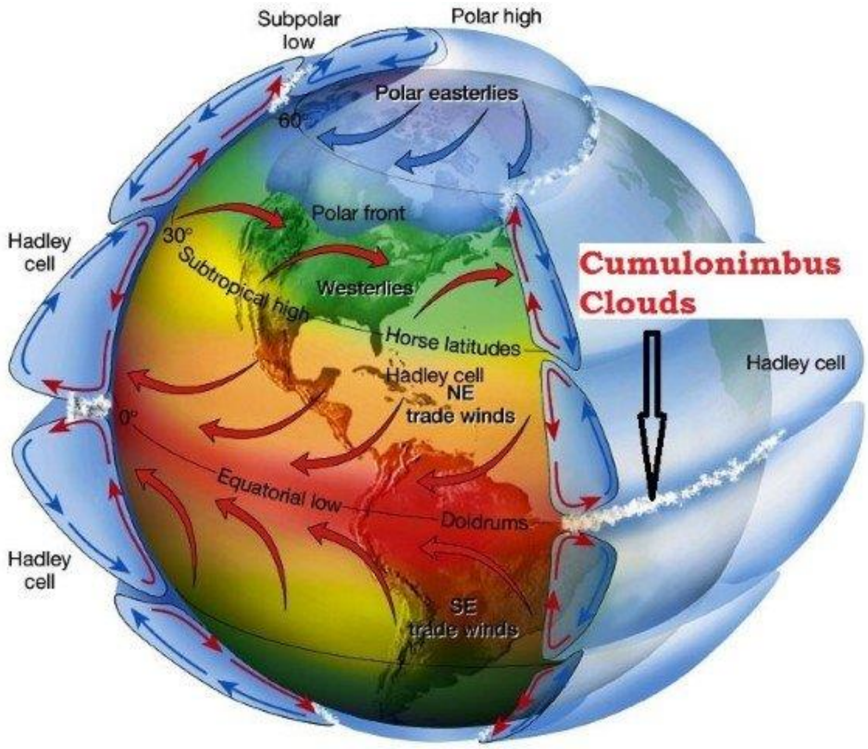


Pressure belts in January

- During winter, the conditions are reversed, and the pressure belts shift south of their 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.

Module 05: Winds

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



General Circulation

5.1 Hadley Cell

- The air at the equatorial low-pressure belt rises because of the convection currents.
- The air 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.
- At the surface a component of the diverging wind from the subtropical high flows towards the equator as the **easterlies (northeast to southwest)**.
- The easterlies from either side of the equator converge at the equatorial low pressure and the cycle repeats.
- Such circulations of wind is called a cell. Such a cell in the tropics is called **Hadley Cell.**

5.2 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.**

5.3 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.

5.4 Classification of Winds

5.4.1 Permanent winds or Primary winds or Prevailing winds or Planetary Winds

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

5.4.2 Secondary or Periodic Winds

- ❑ Seasonal winds: These winds change their direction in different seasons. E.g. Monsoons in South Asia.
- ❑ Periodic winds: **Land and sea breeze, mountain and valley breeze** etc.

5.4.3 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.

5.4.1.1 Primary winds or Planetary Winds

- The winds blowing almost in the same direction throughout the year are called prevailing or permanent winds.
- These are also called as invariable or planetary winds because they involve larger areas of the globe.
- The two most significant winds for climate and human activities are **trade winds** and **westerly winds**.

5.4.1.2 The Trade Winds

- The trade winds are those blowing from the **sub-tropical high-pressure** areas towards the **equatorial low-pressure belt**.
- Therefore, these are confined to a region between **30°N and 30°S** throughout the earth's surface.
- They flow as the **north-eastern trades** in the northern hemisphere and the **south-eastern trades** in the southern hemisphere.
- 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 near 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.

5.4.1.3 The Westerlies

- The westerlies are the winds blowing from the **sub-tropical high-pressure belts** towards the **sub-polarlow-pressure belts**.
- They blow from **southwest to northeast** in the northern hemisphere and **northwest to southeast** 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.
- These winds produce **wet spells** and variability in weather.

5.4.1.4 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 **high-pressure polar** areas of the **sub-polar lows**.

5.4.2 Secondary Winds or Periodic Winds

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

5.4.2.1 Monsoons

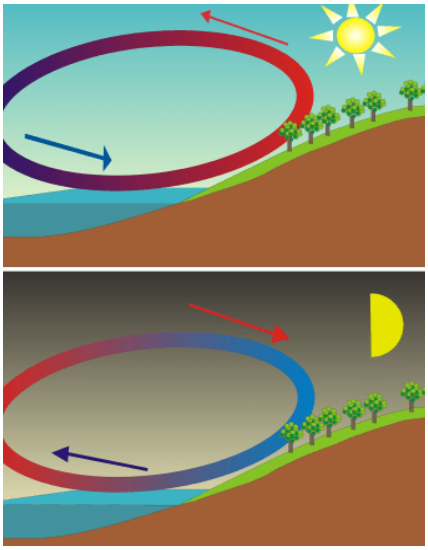
- Monsoons were traditionally explained as **land and sea breezes on a large scale.**
- They were earlier considered as a **convectional circulation on a giant scale.**
- The monsoons are characterized by **seasonal reversal** of wind direction.
- During summer, the trade winds of southern hemisphere 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.
- 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 **anti-cyclonic 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.

Indian Monsoon seasonal wind direction

- The monsoon winds flow over India, Pakistan, Bangladesh, Myanmar (Burma), Sri Lanka, the Arabian Sea, Bay of Bengal, south-eastern 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.

5.4.3 Land Breeze and Sea Breeze

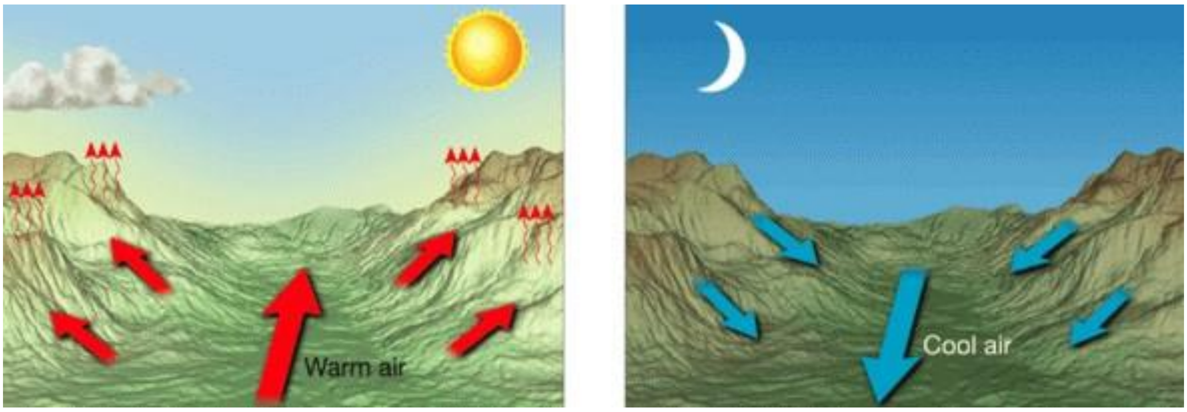
- During the day the land heats up faster and becomes warmer than the sea.
- Therefore, over the land, the air rises giving rise to a low-pressure area, whereas the sea is relatively cool and the pressure oversea is relatively high.
- Thus, pressure gradient from sea to land is created,and the wind blows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



Land Breeze and Sea Breeze (Ingwik, via Wikimedia Commons)

5.4.4 Valley Breeze and Mountain Breeze

- In mountainous regions, during the day the slopes get heated up, and air moves upslope.
- The air from the valley blows up the valley to fill the resulting gap. 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 (high-density air flowing down the slope).**



Valley Breeze and Mountain Breeze (Credits)

5.4.5 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.

5.4.5.1 Loo

- In the plains of northern India and Pakistan, sometimes a very hot and dry wind blows from the west in **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.

5.4.5.2 Foehn or Fohn

- 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**.

5.4.5.3 Chinook

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

5.4.5.4 Mistral

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

5.4.5.5 Sirocco

- 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.

Major Local Winds across the world

Cold Wind	Warm Wind
Pampero	***Foehn***
Gregale	***Chinook***
Bora	***Zonda***
Tramontane	***Loo***
Mistral	***Sirocco***

Loo	Hot	Harmful	Plains of northern India and Pakistan
Mistral	Cold	Harmful	Rhine valley – Southern France
Sirocco	Hot	Harmful	Mediterranean wind that comes from the Sahara
Fohn	Hot	Beneficial	Leeward side of Alps
Chinook	Hot	Beneficial	Leeward side of Rockies

5.4.5.5.1 Prelims Practise

1. 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-clockwise (b) perpendicular to isobars (d) parallel to isobars

Answers: 1) c. 900 mb; 2) a. Equator 3) c. anti-clockwise

5.4.5.5.2 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?(Hint: Coriolis force)
2. What are the geostrophic winds?
3. Explain the land and sea breezes.

5.4.5.5.3 150 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?

1.TROPICAL CYCLONE AND TEMPERATE CYCLONES

2. CYCLONES:-

3.Cyclones are centers of low pressure surrounded by closed isobars having increasing pressure outward and closed air circulation(convergent air circulation) from outside towards the central low pressure in such a way that winds blow in antic clockwise and clockwise directions in the northern and the southern hemisphere respectively.

4. TYPES OF CYCLONES:- There are two types of cyclones based on forms of locations are as:-

There are two types of cyclones based on forms of locations are as:-

2. 5.1. Tropical cyclones and 2. Temperate cyclones (extratropical cyclones)

6.Tropical cyclones:- cyclones developed in the regions lying between the tropics of Capricorn and Cancer are called tropical cyclones, which are not regular and uniform. The tropical cyclone is powerful manifestation of the Earth's energy and moisture system. They originate entirely within the tropical air masses. The weather conditions of low latitudes mainly rainfall regimes are largely controlled by cyclones.

1.ORIGINE OF TROPICAL CYCLONES:- The mechanism that leads to the origin and development of tropical cyclones is not fully known due to the inadequacy of data. There are, certain conditions which result in the origin of tropical cyclones. These conditions are:- large and continuous supply of warm and moist air. large value of coriolis force. weak vertical wind. large value of coriolis force. weak vertical wind. upper level anticyclone presence of anticyclonic circulation. In tropical cyclones, cyclonic motion begins with slow moving easterly waves of low pressure in the trade wind belt of the tropics, such as the Caribbean Sea and the China Sea.

2. **MAIN CHARACTERISTICS OF TROPICAL CYCLONES**:- Following are the main characteristics of tropical cyclones:I. They have circular and enclosed isobars. II. The isobars are close to each other and consequently, the isobaric gradient is steep. III. Their diameter varies between 150 and 300 km.III. Their diameter varies between 150 and 300 km. IV. In initial stage their speed varies between 15 and 30 kmph which accelerates subsequently up to 200 km and even more per hour. V. Heavy rainfall continues even after the winds have become weak.

3.DESIGNATION WINDS FEATURES Tropical Disturbance Variable low Definite area surface low pressure, patches of clouds Tropical Depression Up to 34 kmph Gale force, organising circulation, light to

4.CLASSIFICATION OF TROPICAL CYCLONES circulation, light to moderate rain. Tropical Storm 35 to 64 kmph Close isobars, definite circular organization, heavy rain, Hurricane(Atlantic and Pacific), Cyclones Indian Ocean, Willy willy(Northern Australia). 40 to 200 kmph steep gradient, cumulus- nimbus clouds, heavy rains, thunder and lightning.

ORIGINE OF TROPICAL CYCLONES:-

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- ❖ large and continuous supply of warm and moist air.
- ❖ large value of coriolis force.
- ❖ weak vertical wind.
- ❖ upper level anticyclone
- ❖ presence of anticyclonic circulation.

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CLASSIFICATION OF TROPICAL CYCLONES

DESIGNATION	WINDS	FEATURES
Tropical Disturbance	Variable low	Definite area surface low pressure, patches of clouds
Tropical Depression	Up to 34 kmph	Gale force, organising circulation, light to moderate rain.
Tropical Storm	35 to 64 kmph	Close isobars, definite circular organisation, heavy rain,
Hurricane(Atlantic and Pacific), Cyclones Indian Ocean, Willy willy(Northern Australia).	40 to 200 kmph	steep gradient, cumulus-nimbus clouds, heavy rains, thunder and lightning.

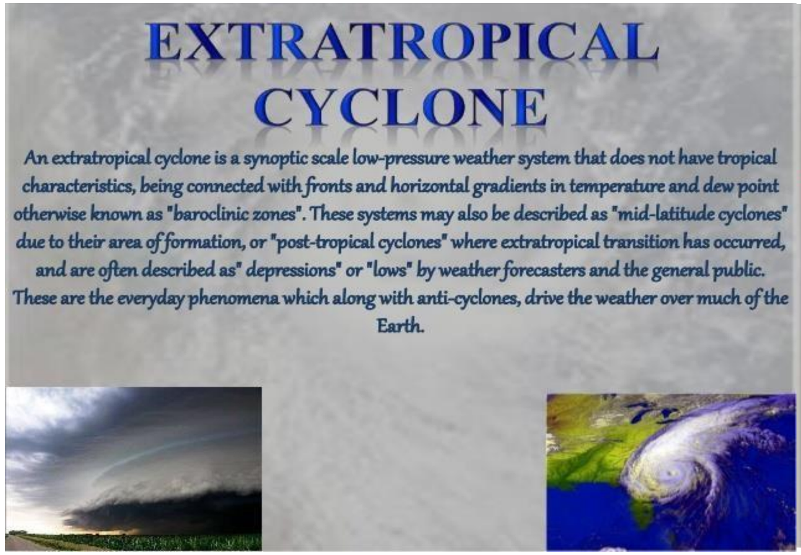
3. Temperate cyclones

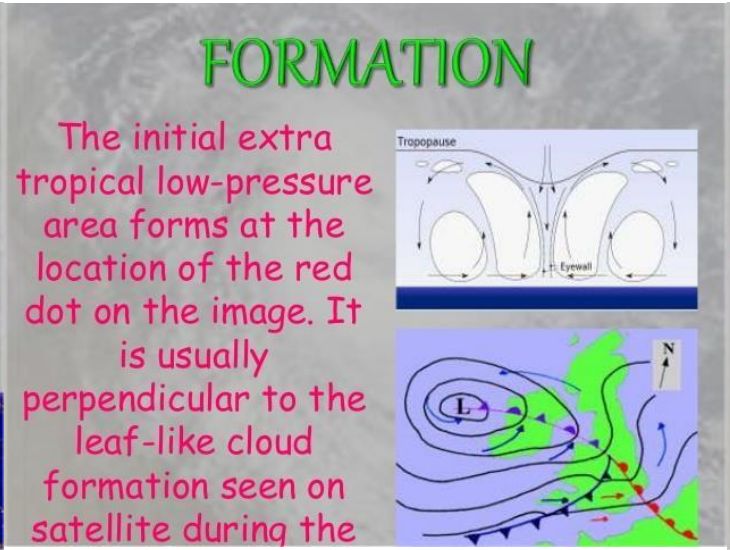
Temperate cyclones are cold cored, and winds increase with height. Tropical cyclones have much more intense rainfall that temperate cyclones, since deep convection is their source of energy. Temperate cyclones tend to have more moderate rainfall, although in extreme cases still enough to cause destructive flooding.

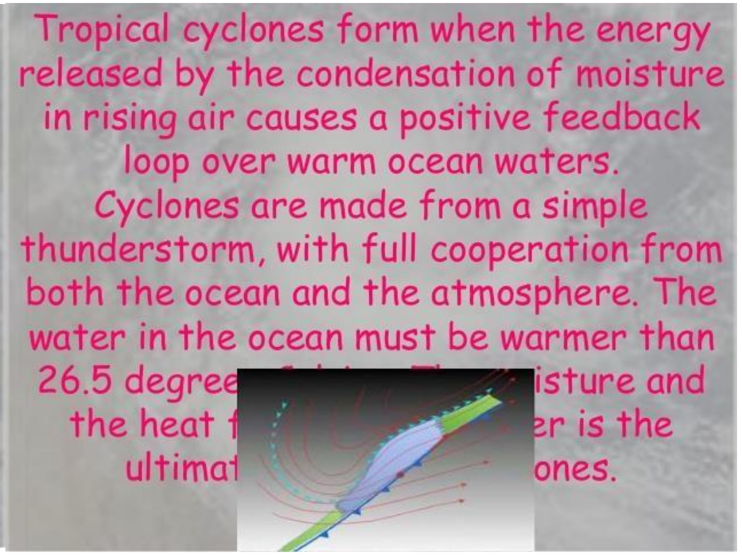
Tropical cyclones have strongest winds in the lower troposphere, near the top of the boundary layer, a few hundred meters above the ground.

Temperate cyclones have their strongest winds at the top of the troposphere in the core of cyclones have their strongest winds at the top of the troposphere in the core of the jet stream.

There are many differences between these two cyclones like intensity, wind speed, eye diameter, maximum spatial and temporal extent of cyclone, landfall etc.. but Main differences among all are Source and the place where do they form. based on these two only they got named like tropical and temperate cyclones.







1.TEMPERATE CYCLONES(EXTRA-TROPICAL CYCLONES):- Temperate cyclones, also called as extra tropical cyclones or wave cyclones or simply depressions are atmospheric disturbances having low pressure in the center and increasing pressure outward. The convergence of the cold front and the warm front in the temperate latitude cyclones conducive for the development of mid-latitude cyclone. The development and strengthening of a mid-latitude ware cyclone id known as cyclogenesis. They move counterclockwise in the Northern hemisphere and clockwise in the southern hemisphere. The temperate cyclonic motion is generated by the pressure gradient force, the coriolis force, and the surface friction force. The temperate cyclone takes 3-10 days to complete its cycle from birth, maturity, and death.

2. ORIGINE OF TEMPERATE CYCLONES:- The first pioneer serious attempt was made by Fitzroy in the year 1863 in this precarious field. He postulated that extra tropical or temperate cyclones originated because of the convergence of two opposing air masses of contrasting physical properties i.e. temperature, pressure, density and humidity.

1.POLAR FRONT THEORY The Polar Front Theory was propounded by Bjerkines in 1918. it deals with the stages of development of temperate cyclones. According to Bjerknes, a cyclone originates through the following six stages.Bjerknes, a cyclone originates through the following six stages. Stage I:- Involves the convergence of two air masses of contrasting physical properties and directions. Initially , the air masses move parallel to each other and a stationary front is formed. This is called initial stage. Stage II:- is also called as 'incipient stage' during which the warn and cold air masses penetrate into the territories of each other and thus a wave-line front id formed. Stage II:- is the mature stage when the cyclone is fully developed and isobars become almost circular.

2. Stage IV:- warm sector is narrowed in extent due to the advancement of cold front than warm extent due to the advancement of cold front than warm front, as cold front comes nearer to warm front. Stage V:- starts with the occlusion of cyclone when the advancing clod front finally overtakes the warm front and an occluded front is formed. Stage VI:- warm sector completely disappears , occluded front is eliminated and ultimately cyclone dies out.

3.1 1. CHARACTERRISTICS OD A TEMPERATE CYCLONE:-

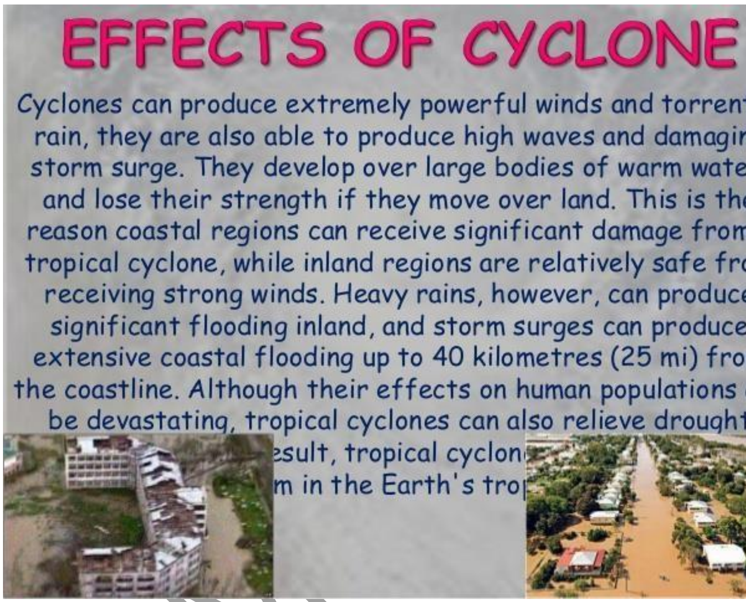
2.Following are the main characteristics of a temperate cyclone:- i. The temperate cyclones may be more than 1600 km in diameter. ii. The isobars of a temperate cyclone are generally elongated or oval shaped. iii. They change their path with season. In the winter season they adopt a more southerly course covering the Mediterranean Sea, wile in summer they move northward giving no rainfall in the Mediterranean region. iv. Their general direction of movement is from west to east. v. They are human friendly. The lightshowers of he temperate cyclone is highly effective and beneficial for the agricultural actives and human efficiency.

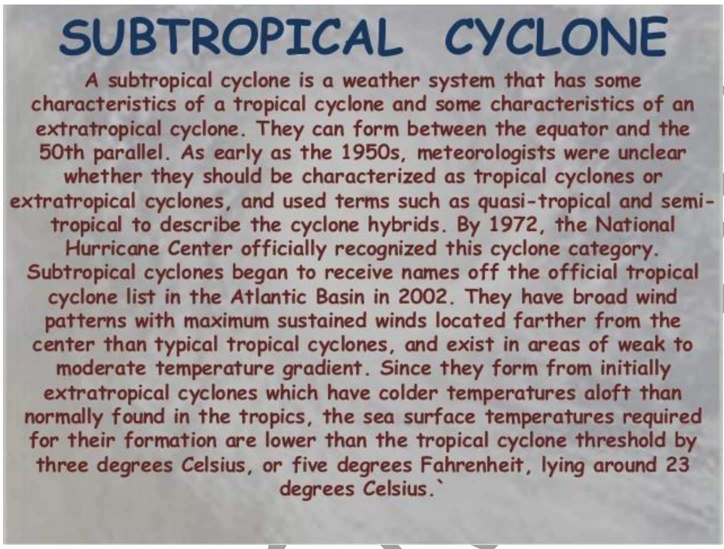
3.9. What is the difference between tropical and temperate cyclones? Major differences between cyclones in Tropical and

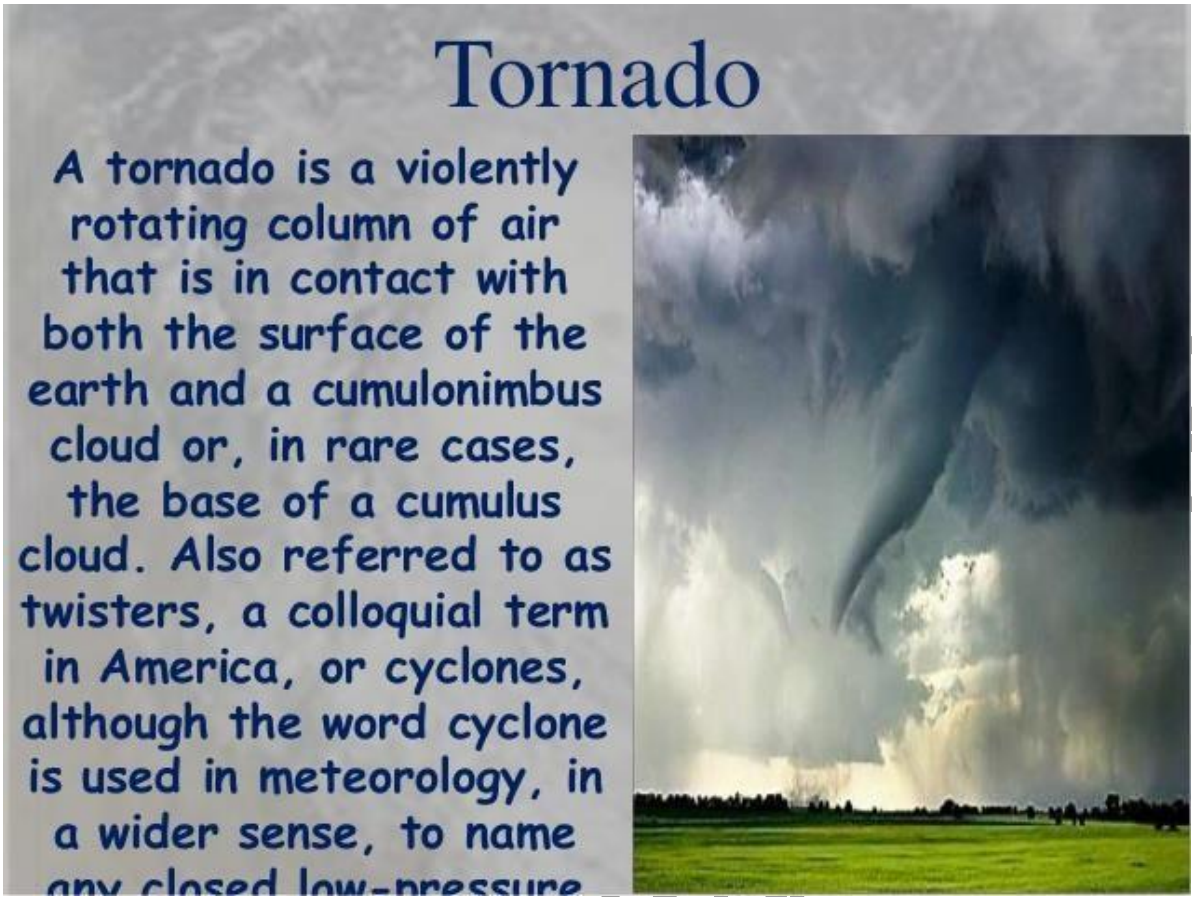
|Temperature climates. In general, the cyclones which form in tropical regions (0–30° N and 0– 30°S) are called tropical cyclones. The cyclones which form in Temperate regions (30–60°N and 30–60°S) are called Temperate cyclones. One of the major differences between these is 'source' to form a cyclone.One of the major differences between these is 'source' to form a

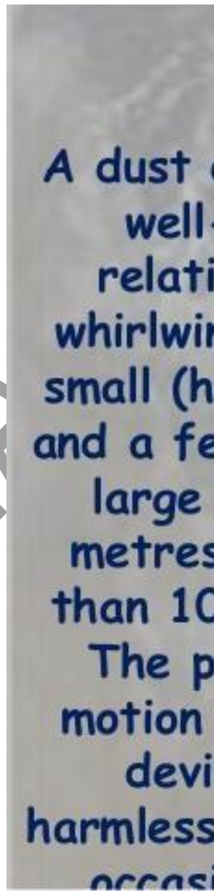
cyclone. i.e. in tropical regions, cyclones generally form by thermal convection but, whereas in temperate climates, cyclones form by fronts (Boundary between two different air masses). Tropical cyclones are mesoscale weather systems, the diameter of the storm is of the ordera few hundred km. Temperate cyclones are synoptic scale systems, thousands of km across.

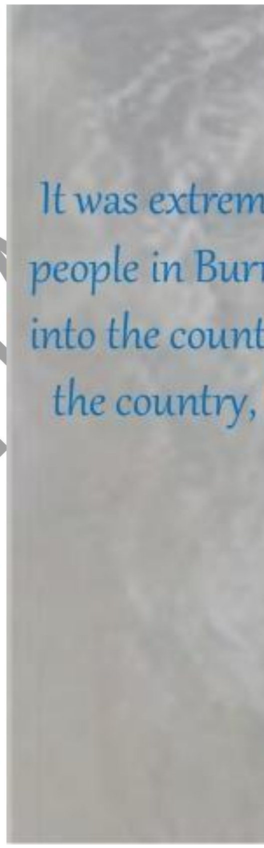

NARGIS
Cyclone Nargis is the deadliest tropical storm in the recorded history of Burma (Myanmar). It devastated many areas in Burma, as well as some areas in Sri Lanka, Bangladesh and India.


EFFECTS OF CYCLONE
Cyclones can produce extremely powerful winds and torren
rain, they are also able to produce high waves and damagi
storm surge. They develop over large bodies of warm wate
and lose their strength if they move over land. This is th
reason coastal regions can receive significant damage from
tropical cyclone, while inland regions are relatively safe fr
receiving strong winds. Heavy rains, however, can produc
significant flooding inland, and storm surges can produce
extensive coastal flooding up to 40 kilometres (25 mi) fr
the coastline. Although their effects on human populations
be devastating, tropical cyclones can also relieve drough


SUBTROPICAL CYCLONE
A subtropical cyclone is a weather system that has some characteristics of a tropical cyclone and some characteristics of an extratropical cyclone. They can form between the equator and the 50th parallel. As early as the 1950s, meteorologists were unclear whether they should be characterized as tropical cyclones or extratropical cyclones, and used terms such as quasi-tropical and semi-tropical to describe the cyclone hybrids. By 1972, the National Hurricane Center officially recognized this cyclone category. Subtropical cyclones began to receive names off the official tropical cyclone list in the Atlantic Basin in 2002. They have broad wind patterns with maximum sustained winds located farther from the center than typical tropical cyclones, and exist in areas of weak to moderate temperature gradient. Since they form from initially extratropical cyclones which have colder temperatures aloft than normally found in the tropics, the sea surface temperatures required for their formation are lower than the tropical cyclone threshold by three degrees Celsius, or five degrees Fahrenheit, lying around 23 degrees Celsius.`


Tornado
A tornado is a violently rotating column of air that is in contact with both the surface of the earth and a cumulonimbus cloud or, in rare cases, the base of a cumulus cloud. Also referred to as twisters, a colloquial term in America, or cyclones, although the word cyclone is used in meteorology, in a wider sense, to name any closed low-pressure





Meaning of Humidity:

Humidity is a general term which indicates the amount of water vapours in the air. There is a close relationship between humidity and the temperature of air. The capacity of the air to contain water vapour depends upon the temperature. The water holding capacity of air increases with increase in temperature. Higher the temperature, higher is the water holding capacity of air.

As the temperature increases, the water holding capacity increases slowly at low temperature, and later on it increases very fast at high temperature. At any time of the day, there exists a difference between saturation vapour pressure and actual vapour pressure. This is called saturation deficit.

This deficit is very high during dry, summer days and very low during rainy days. Because of minimum temperature during morning hours, the water holding capacity is very low, therefore, maximum humidity is found in the morning. On the other hand, the air temperature is maximum in the afternoon, therefore, low humidity is found in the afternoon.

When the water vapours enter into the air, the air becomes warm, humid and lighter. We know that the molecular weight of the water vapours is less as compared to the dry air. Water vapours carry sensible heat, therefore, as the amount of water vapours increases, the sensible heat of the air also increases.

As a result, air becomes warm, humid and lighter. The lighter air is more buoyant and acquires the capacity to move in the upward direction. If the convection currents are strong, the upward movement of humid air becomes very fast.

Types of Humidity:

(i) Relative humidity,
(ii) Specific humidity,
(iii) Mixing ratio, and
(iv) Absolute humidity.

i. Relative Humidity:

The measure of humidity is generally called relative humidity. Saturation mixing ratio is used to determine relative humidity. It is defined as the amount of water vapours in grams available in one kilogram of dry air. One of the most important measure of humidity is dew point.

Dew Point Temperature:

The temperature to which air must be cooled in order to reach saturation is called dew point.

Frost Point Temperature:

When the dew point is below 0°C, the water vapours change directly from gaseous to solid state leading to the formation of ground frost. Thus frost point temperature is the temperature at which frost occurs. In fact, frost is the deposition of ice crystals on a cooler ground surface or grass surface by diffusion or sublimation process. This occurs when the dew point and air temperature fall below freezing level.

Wet-Bulb Temperature:

Wet bulb temperature of the moist air at pressure ‘p’, temperature ‘T’ and mixing ratio ‘r’ is the temperature at which the air attains saturation when water is introduced through small amounts at the current temperature and evaporated into the air by adiabatic process at constant pressure until saturation is reached.

Condensation:

When the air becomes saturated, the water holding capacity becomes negligible. When the temperature decreases, the water vapour of the saturated air changes to liquid water. This temperature is known as dew point. The process is called condensation. Thus condensation is defined as the process in which water vapours change from gaseous state to liquid state when the dew point remains above 0°C.

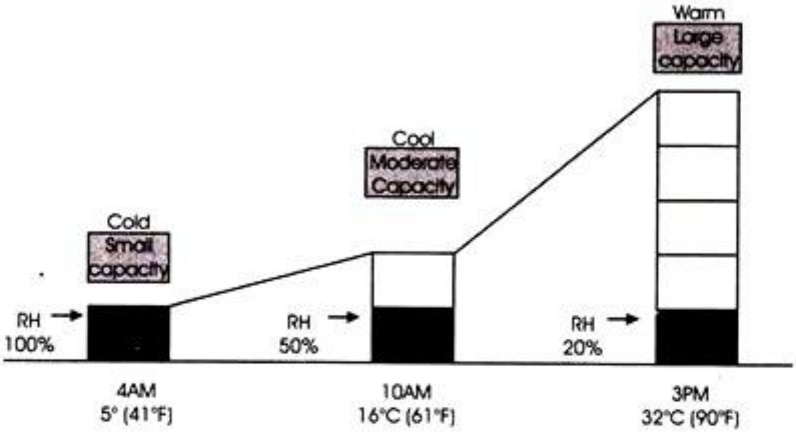
It is defined as the process in which water vapours change directly from gaseous state to solid state when the dew point falls below 0°C. e.g. frost.

The dew point temperature is based on how much water vapour is in the air. So while dew point is given in terms of temperature, it is actually a measure of humidity.

We can use the chart to explain one of the most important measures of humidity, the dew point. Let us suppose that at 3 p.m. on a particular day, the temperature is 32°C. The air has 10.83gm of water vapours per kilogram of dry air. The chart shows that at 5°C air is saturated, if it has 10.83gm of water vapours per kilogram.

If air becomes copier, the water vapour will begin condensing into liquid water. Dew will form on the grass. It indicates that if air is cooled below 5°C, it will be saturated and dew will form. In other words, 5°C is the dew point.

Relative humidity depends not only on how much water vapour is in the air but also on the air temperature. The following table indicates the relative humidity at different temperatures.



Relative humidity (RH) is always expressed as percentage. Suppose an air mass of 1kg contains 9gm of water vapours at a given temperature and constant pressure. But 1kg of an air mass has the capacity to contain 12gm of water vapours at the same temperature and pressure.

∴ RH = 9/12 x 100 = 75%

Relative humidity may also be defined as the ratio of actual vapour pressure to that required for saturation at the same temperature.

$$RH = \frac{\text{Actual vapour pressure}}{\text{Saturation vapour pressure}} \times 100$$

or

$$RH = \frac{e}{e_s} \times 100$$

Relative humidity tends to be higher during winter over land, except during monsoon period. Relative humidity is higher over the oceans during summer season.

ii. Specific Humidity:

It is the ratio of mass of water vapours actually present in the air to a unit mass of air including the water vapour (dry air + moisture). It is expressed as grams of water vapour per kg of moist air mass. The amount of water vapour that air can hold depends upon temperature. Specific humidity at 20°C is 15g per kg. At 30°C, it is 26 g per kg and at -10°C, it is 2 g per kg.

Suppose, 1kg of air contains 12 grams of water vapours, then the specific humidity of air is 12 g per kg.

Specific humidity is a constant property of air, therefore, it is frequently used in meteorology. The value of the specific humidity changes only if the amount of water vapours undergoes any change. But it is not affected by the changes in pressure or temperature of air. It is directly proportional to the vapour pressure of air and inversely proportional to the atmospheric pressure.

Specific humidity is maximum over the equator and minimum over poles. In a particular region, specific humidity is higher in summer than in winter, but it is higher over the oceans than over the land. The specific humidity of dry air over arctic regions in winter may be as low as 0.2 g per kg.

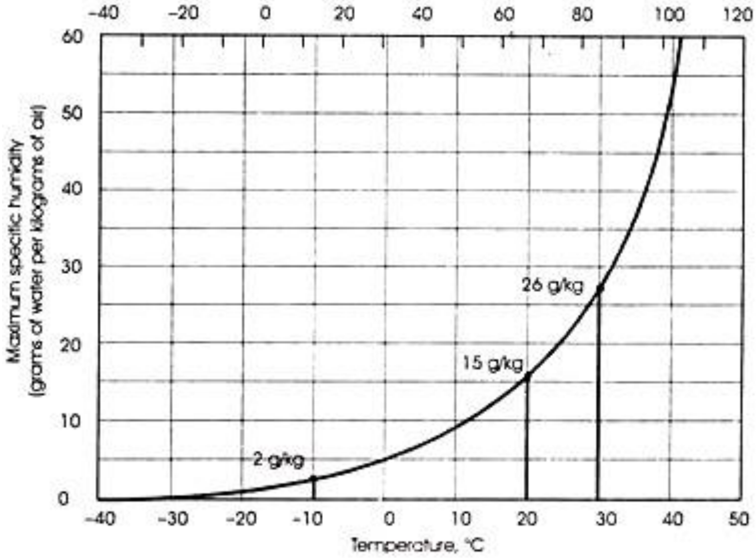
Importance of Humidity:

There is a close relationship between humidity and temperature. Low humidity and high temperature conditions accelerate the water demand of the crop plants. Under these conditions, the evaporation increases. If sufficient water is not available for the normal growth of crop plants, water is supplemented by providing additional irrigation.

But under rainfed conditions, the crop plants suffer due to water stress generated by low humidity and high temperature conditions. If the moisture stress happens to be at the reproductive phase, the grain yield of the rainfed crop reduces drastically.

Similarly, humidity and temperature play an important role in the spread of insects, pests and diseases. High humidity and high temperature conditions make the air humid, which is most favourable for the incidence of plant diseases.

High humidity can occur during rainy season due to enormous amount of water vapours and also during winter season when the temperature is low as compared to monsoon season. Therefore, the intensity of insects, pests and diseases is more during monsoon season as compared to winter season.



iii. Mixing Ratio:

It is defined as the ratio of mass of water vapours per unit mass of dry air. It is also defined as the ratio of density of water vapours to the density of dry air. It varies from 1 g per kg in arctic zone to 40 g per kg in humid equatorial zone.

iv. Absolute Humidity:

It is defined as the weight of water vapours in a given volume of air. It is expressed as grams of water vapours per cubic meter of air (g m^{-3}). Absolute humidity is rarely used because it varies with the expansion and contraction of air. It varies with temperature, even though the amount of water vapours remains constant.

What does dew point indicate?

When water vapour changes into liquid or directly into ice, it releases latent heat to the air and warms the air slightly. During night, air cools and gets saturated. The temperature at which air has to be cooled in order to reach the saturation, is called dew point.

Therefore, as the air cools to its dew point, condensation starts releasing latent heat of condensation. This latent heat slows down the temperature decrease. As a result, the air is not likely to get colder than its initial dew point any time during the night.

During winter season, if the air temperature and dew point are closer together in the late afternoon as the air turns cooler, fog is likely to occur during the night. It has been found that if the difference between the air temperature and dew point is less than 5°C, the fog is likely to occur.

CLASSIFICATION OF CLOUDS

Meteorologists use the term ‘**parcel**’ to define a small body of air. Temperature and humidity conditions define a parcel’s ability to take off from the ground. Stability refers to the tendency of a parcel of air with its water vapor to either remain stationary or to ascend or descend. A stationary parcel is called Stable while an Ascending or descending parcel is called unstable.

An air parcel is considered unstable when it continues to rise until it reaches an altitude where the surrounding air has density similar to its own.

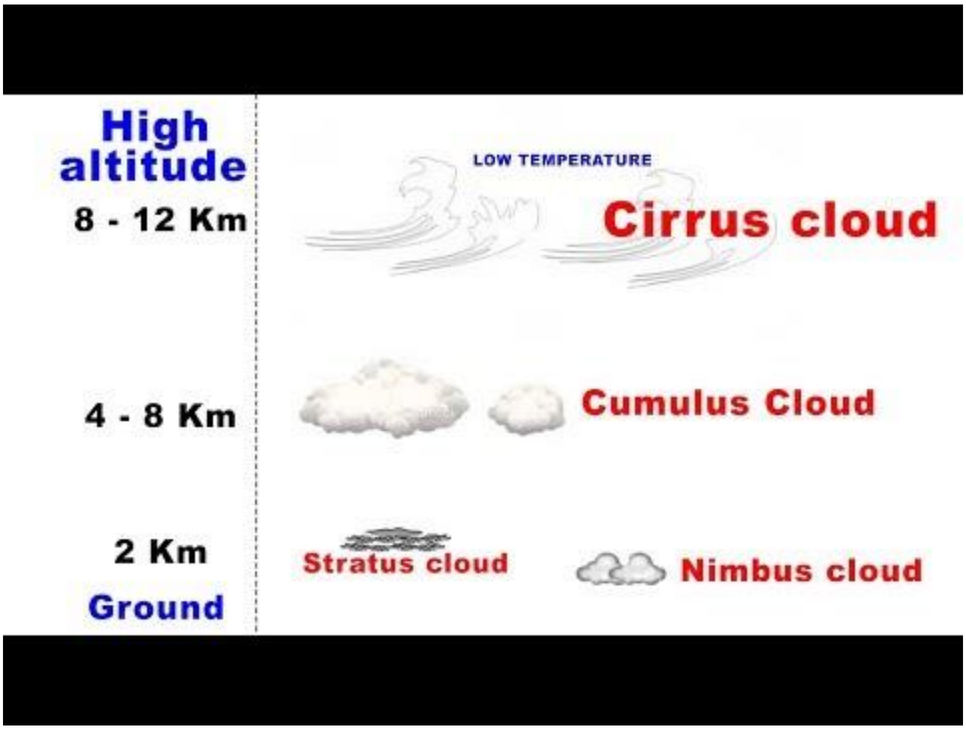
As a parcel ascends its pressure decreases with height. Due to a decrease in pressure, there is a drop in the temperature of the air parcel. As there is no external heat exchange, the process is called the **Adiabatic process**. As the temperature is reduced, it is called adiabatic cooling.

The point to be remembered is that it is different from the environmental lapse rate. In the case of the environmental lapse rate, the temperature decrease with an increase in altitude but the air is not moving from its place. In the case of Adiabatic cooling, the air parcel itself is moving and there is a drop of temperature in an air parcel. The rate of change of temperature is called the Adiabatic rate of cooling.

Similarly, as the parcel descends, the pressure in parcel increases hence there is an increase in temperature. This is called Adiabatic heating.

Condition for instability: When the Adiabatic lapse rate of cooling is lower than the local lapse rate, there is a condition for unstable air.

Cloud formation occurs when there is an unstable air condition. As the air rises it starts cooling adiabatically. As the humidity present in it is in vapour form, it is called the dry adiabatic rate. As the temperature reaches the dew point, the vapor starts condensing into small droplets forming clouds. The height in which the condensation starts is called the **condensation limit**. If the parcel is still unstable it will rise more, now because liquid water is present, it is wet adiabatic cooling. The wet adiabatic rate is higher than the dry adiabatic rate.



Clouds formation

- Clouds form when the invisible water vapor in the air condenses into visible water droplets or ice crystals.
- There is water around us all the time in the form of tiny gas particles, also known as water vapour.
- There are also tiny particles floating around in the air – such as salt and dust – these are called aerosols.
- The water vapour and the aerosols are constantly bumping into each other.

- When the air is cooled, some of the water vapour sticks to the aerosols when they collide – this is condensation.
- Eventually, bigger water droplets form around the aerosol particles, and these water droplets start sticking together with other droplets, forming clouds.
- Clouds form when the air is saturated and cannot hold any more water vapour, this can happen in two ways:
- The amount of water in the air has increased – for example through evaporation – to the point that the air cannot hold any more water.
- The air is cooled to its dew point – the point where condensation occurs – and the air is unable to hold any more water.
- The warmer the air is, the more water vapour it can hold.
- Clouds are usually produced through condensation – as the air rises, it will cool and reducing the temperature of the air decreases its ability to hold water vapour so that condensation occurs.
- The height at which dew point is reached and clouds form is called the condensation level.

What causes clouds to form?

There are five factors that can lead to air rising and cooling and clouds forming.

1. Surface heating
2. Orographic barrier
3. Fronts
4. Convergence
5. Turbulence

1. **Surface heating** – This happens when the ground is heated by the sun which heats the air in contact with it causing it to rise. The rising columns are often called thermals. Surface heating tends to produce cumulus clouds.

2. **Topography or orographic forcing** – The topography – or shape and features of the area – can cause clouds to be formed. When air is forced to rise over a barrier of mountains or hills it cools as it rises. Layered clouds are often produced this way.

3. **Frontal –** Clouds are formed when a mass of warm air rises up over a mass of cold, dense air over large areas along fronts. A 'front' is the boundary between warm, moist air and cooler, drier air.

4. **Convergence** – Streams of air flowing from different directions are forced to rise where they flow together, or converge. This can cause cumulus cloud and showery conditions.

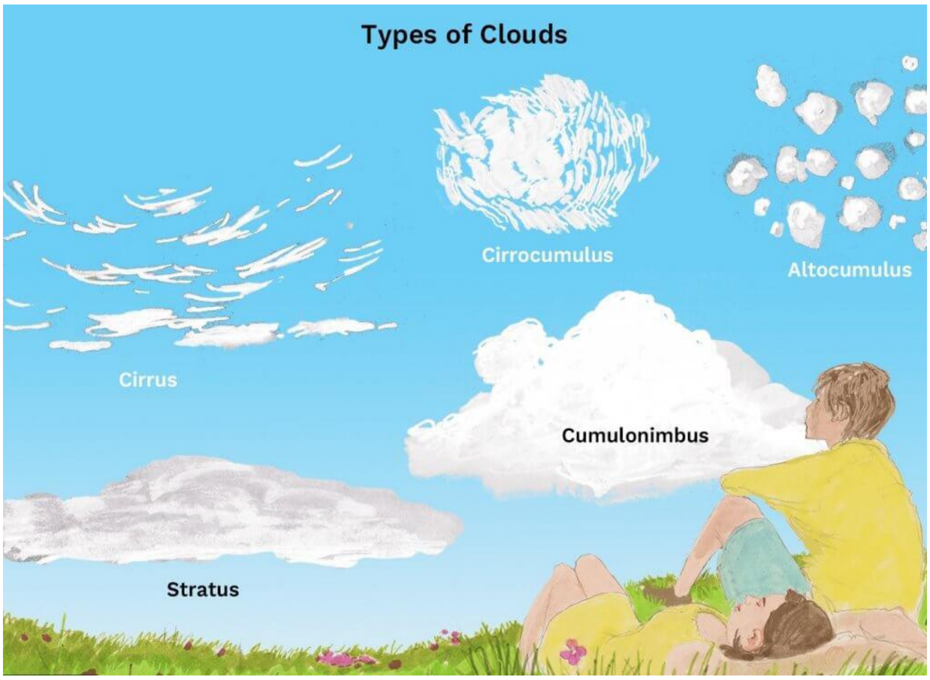
5. **Turbulence** – A sudden change in wind speed with height creating turbulent eddies in the air.

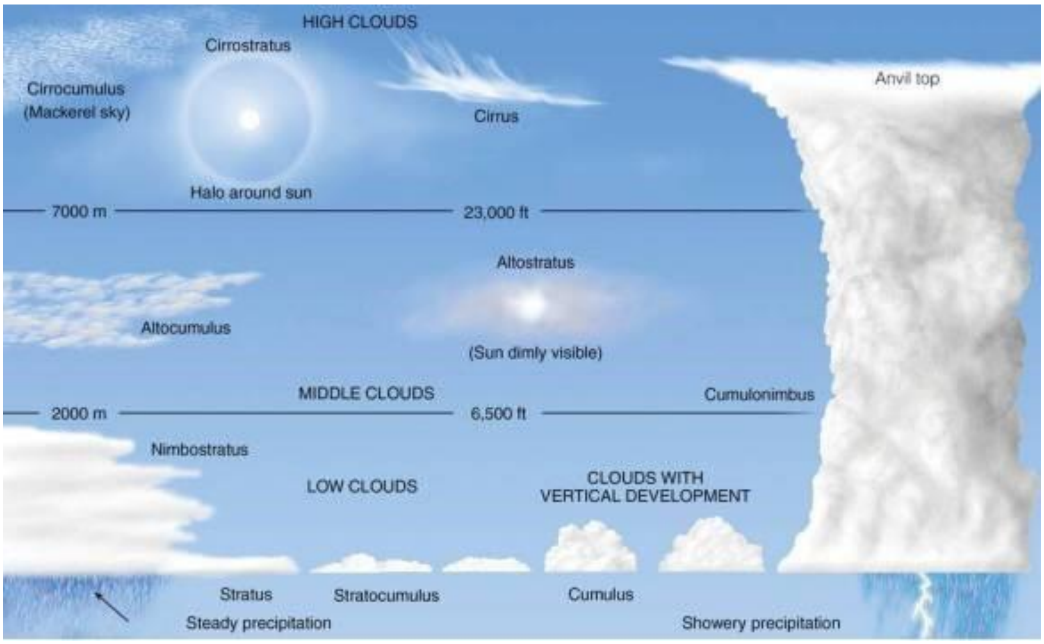
The range of ways in which clouds can be formed and the variable nature of the atmosphere results in an enormous variety of shapes, sizes and textures of clouds.

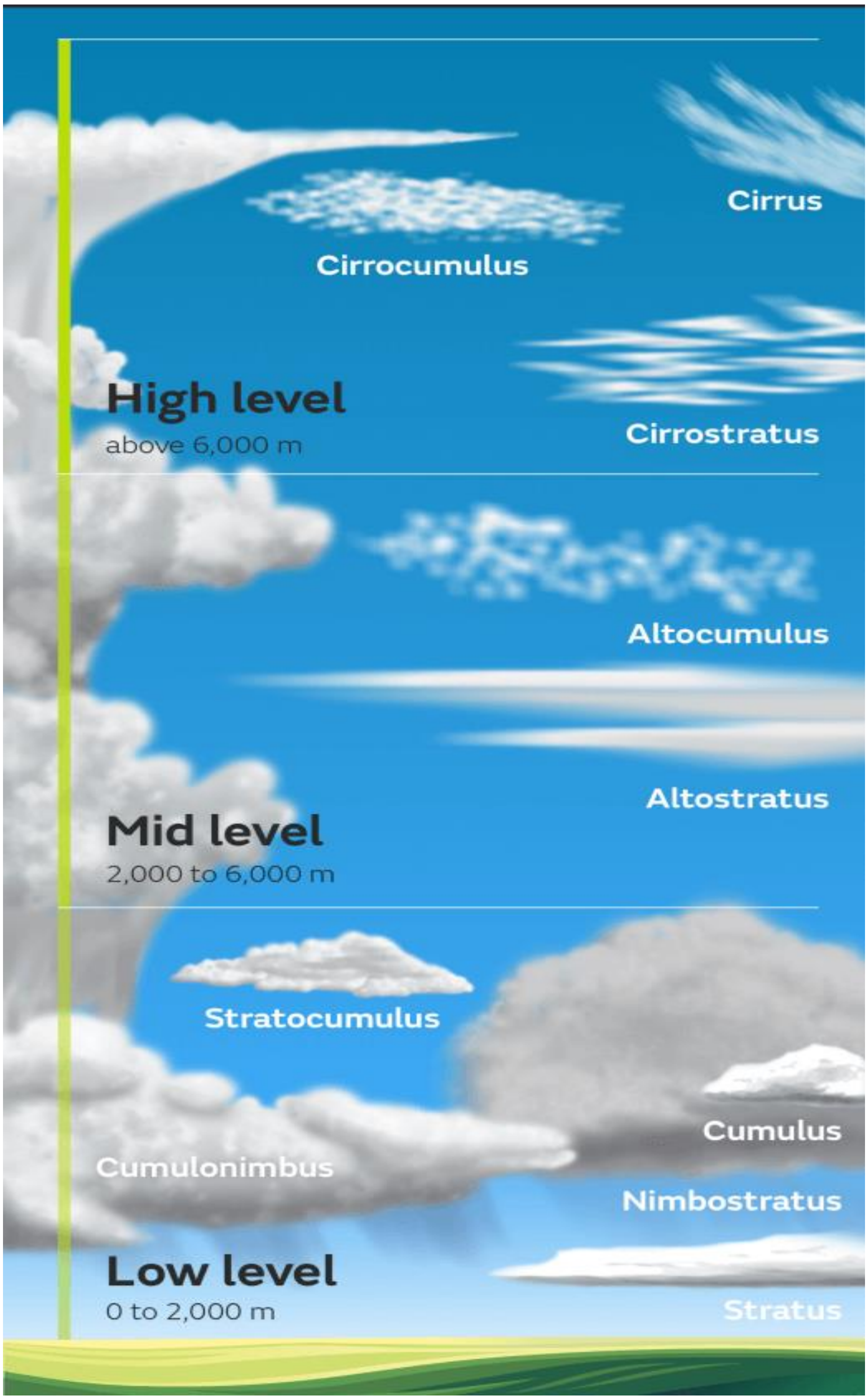
Types Of Clouds

There are **four basic cloud** categories observed in our atmosphere –

1. Cirrus
2. Cumulus
3. Stratus
4. Nimbus


Types of Clouds
Cirrocumulus
Altocumulus
Cirrus
Cumulonimbus
Stratus


HIGH CLOUDS
Cirrostratus
Cirrocumulus
(Mackerel sky)
Cirrus
Anvil top
Halo around sun
7000 m
23,000 ft
Altostratus
Altocumulus
(Sun dimly visible)
MIDDLE CLOUDS
Cumulonimbus
2000 m
6,500 ft
Nimbostratus
LOW CLOUDS
CLOUDS WITH
VERTICAL DEVELOPMENT
Stratus
Stratocumulus
Cumulus
Steady precipitation
Showery precipitation



The **names for clouds** are usually are combinations of the following prefixes or suffixes:

- **Stratus/strato** = flat/layered and smooth
- **Cumulus/cumulo** = heaped up/puffy, like cauliflower
- **Cirrus/cirro** = High up/wispy
- **Alto** = Medium level
- **Nimbus/Nimbo** = Rain-bearing cloud

A combination of **these four basic types** can **give rise to** the following types of clouds:

Classification of clouds	Types of clouds
High clouds	Cirrus, Cirrostratus, Cirrocumulus
Middle clouds	Altostratus, Altocumulus
Low clouds	Stratocumulus, Stratus, Nimbostratus
Clouds with extensive vertical development	Cumulus, Cumulonimbus

High Altitude clouds: These are found 20,000ft or higher above the land surface. Cirrus, Cirrostratus, and Cirrocumulus are the cloud types found here.
Middle Altitude Clouds: These are found between 6,500ft to 20,000ft above the land surface. Altostratus and Altocumulus are the cloud types found here.
Low Altitude Clouds: These cloud types can be found from ground level to about 6,500ft above it. They include Stratus, Stratocumulus, and Nimbostratus clouds.
Vertical Clouds: These are clouds that extend from the lower to the higher altitude s of the atmosphere. They form by thermal convection or frontal lifting, sustained by the powerful convectional current that holds and pushes the moisture in the clouds further upward. An example of a vertical cloud is the Cumulonimbus cloud.
Foggy Clouds: These form close to the ground. Sometimes they make visibility very poor such that you can hardly see more than 60 away.

Cirrus

- Detached clouds in the form of **white**, delicate filaments, mostly white patches or narrow bands.
- They may have a **fibrous (hair-like) and/or silky sheen appearance.**
- Cirrus clouds are always **composed of ice crystals**, and their transparent character depends upon the degree of separation of the crystals.
- As a rule, when these clouds cross the sun's disk they hardly diminish its brightness. When they are exceptionally thick they may veil its light and obliterate its contour.
- Before sunrise and after sunset, cirrus is often colored bright yellow or red. These clouds are lit up long before other clouds and fade out much later; sometime after sunset, they become gray.
- At all hours of the day, Cirrus near the horizon is often of a yellowish color; this is due to distance and to the great thickness of air traversed by the rays of light.

Cirrostratus

- Transparent, whitish veil clouds with a fibrous (hair-like) or smooth appearance.
- A sheet of cirrostratus which is very extensive, nearly always ends by covering the whole sky.
- A milky veil of fog (or thin Stratus) is distinguished from a veil of Cirrostratus of a similar appearance by the halo phenomena which the sun or the moon nearly always produces in a layer of cirrostratus.

Cirrocumulus

- Thin, white patch, sheet, or layered of clouds without shading.
- They are composed of very small elements in the form of more or less regularly arranged grains or ripples.

Altostratus

- Grey or bluish cloud sheets or layers of striated or fibrous clouds that totally or partially covers the sky.
- They are thin enough to regularly reveal the sun as if seen through ground glass.
- Altostratus clouds do not produce a halo phenomenon nor are the shadows of objects on the ground visible.

Altocumulus

- White and/or grey patch, sheet or layered clouds, generally composed of laminae (plates), rounded masses or rolls.
- They may be partly fibrous or diffuse.

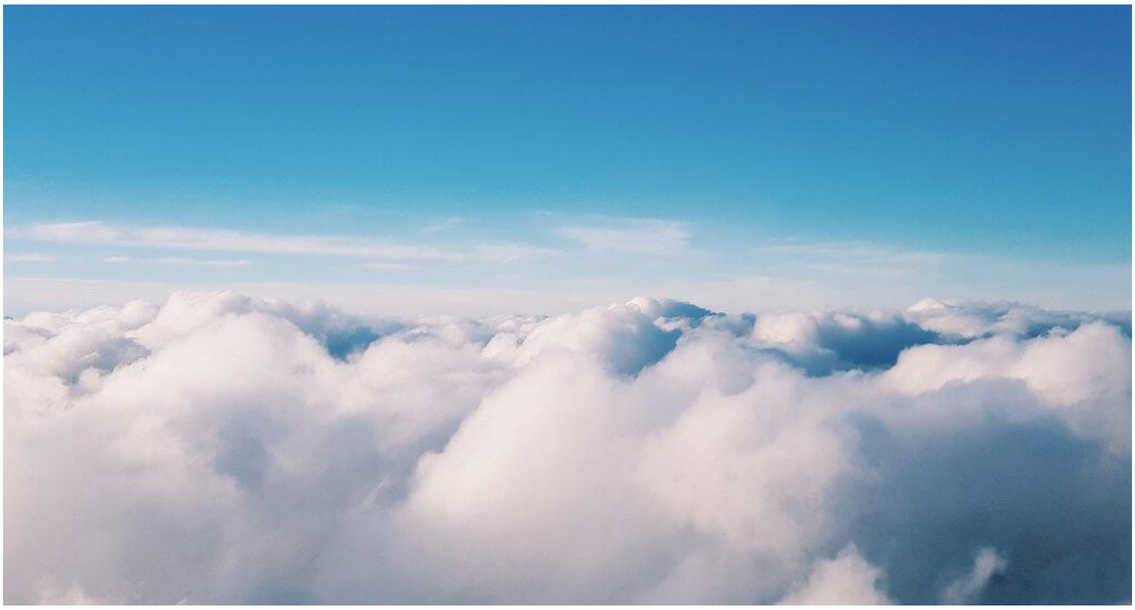
- When the edge or a thin semi-transparent patch of altocumulus passes in front of the sun or moon a corona appears.
- This colored ring has red on the outside and blue inside and occurs within a few degrees of the sun or moon.

Nimbostratus

- The continuous rain cloud. Resulting from thickening Altostratus, This is a dark grey cloud layer diffused by falling rain or snow.
- It is thick enough throughout to blot out the sun.
- The cloud base lowers into the low level of clouds as precipitation continues.

Stratocumulus

- Grey or whitish patch, sheet, or layered clouds which almost always have dark tessellations (honeycomb appearance), rounded masses or rolls.
- Except for virga they are non-fibrous and may or may not be merged.



Stratus

- A generally grey cloud layer with a uniform base which may, if thick enough, produce drizzle, ice prisms, or snow grains.
- When the sun is visible through this cloud, its outline is clearly discernible.
- Often when a layer of Stratus breaks up and dissipates blue sky is seen.

Cumulus

- Detached, generally dense clouds and with sharp outlines that develop vertically in the form of rising mounds, domes, or towers with bulging upper parts often resembling a cauliflower.
- The sunlit parts of these clouds are mostly brilliant white while their bases are relatively dark and horizontal.

Cumulonimbus

- The thunderstorm cloud, this is a heavy and dense cloud in the form of a mountain or huge tower. The upper portion is usually smoothed, fibrous or striated and nearly always flattened in the shape of an anvil or vast plume.
- Under the base of this cloud which is often very dark, there are often low ragged clouds that may or may not merge with the base.
- Cumulonimbus clouds also produce hail and tornadoes.

General points

Do You Know?

Halo (optical phenomenon) – In the form of rings, arcs, pillars, or bright spots, produced by the refraction or reflection of light by ice crystals suspended in the atmosphere (cirriform clouds, diamond dust, etc.)

and, also watch video given below…

Cloud Seeding

Cloud seeding is an artificial way to induce moisture in the clouds so as to cause rainfall. It is done by spreading **either dry ice or more commonly, silver iodide aerosols**, into the upper part of clouds.

There are **three cloud seeding methods-**

- **Hygroscopic cloud seeding** disperses salts through flares or explosives in the lower portions of clouds. The salts grow in size as water joins with them.
- **Static cloud seeding** involves spreading a chemical like silver iodide into clouds. The silver iodide provides a crystal around which moisture can condense.
- **Dynamic cloud seeding** aims to boost vertical air currents, which encourages more water to pass through the clouds, translating into more rain.

Applications of Cloud Seeding

- **Agriculture:** It creates rain, providing relief to drought-stricken areas. E.g.: 'Project Varshadhari' in Karnataka in 2017.
- **Power Generation:** Cloud seeding experiments have shown to augment the production of hydroelectricity during the last 40 years in Tasmania, Australia.
- **Water Pollution Control:** Cloud seeding can help to maintain the minimum summer flow of the rivers and dilute the impact of treated wastewater discharges from municipalities and industries.
- **Fog Dispersal, Hail Suppression, and Cyclone Modification:** "Project Sky Water" of U.S.A. in 1962 for weather modification through cloud seeding aimed at fog dispersal, hail suppression, and cyclone modification. During the winter the cloud seeding program is used to increase the mountain snowpack so that additional runoff is received during the spring melt season. The seeding of cumulus clouds is to provide increased annual rainfall directly on the land.
- **Tackle Air Pollution:** Cloud seeding can potentially be used to settle down toxic air pollutants through the rain. E.g.: recently, Central Pollution Control Board along with other researchers was mulling the use of cloud seeding to tackle Delhi's air pollution.
- **Tourism:** Cloud seeding can transform typically dry areas much more hospitable to enhance tourism.

Challenges

- **Potential Side-effects:** The chemicals used in cloud seeding might be potentially harmful. It does have the potential to harm plants, animals, and people, or the environment as a whole.
- **Abnormal Weather Patterns:** It might ultimately change climatic patterns on the planet. Places that normally receive moisture might start experiencing drought due to the artificial process of adding chemicals to the atmosphere to simulate rain.
- **Expensive:** It involves processes such as delivering chemicals to the sky and releasing them into the air by flare shots or airplanes, which involves huge costs and logistic preparation.

- **Pollution:** As artificial rainfalls, seeding agents like silver iodide, dry ice, or salt will also fall. Residual silver discovered in places near cloud-seeding projects is considered toxic. As for dry ice, it can also be a source of greenhouse gas that contributes to global warming, as it is basically carbon dioxide.

Module 08 (b) Types of Precipitation or Rainfall

Precipitation is the natural process of conversion of atmospheric vapour into water. The water so formed then falls to the earth in the form of a rainfall. In terms of hydrology rainfall constitutes the third phase of atmospheric division of the hydrologic cycle, "the change of state". The term precipitation is also used for rainfall. Precipitation is however, a general term and includes all forms of falling moisture viz., rainfall, snowfall, sleet, hail etc.

During summer season evaporation loss is highly accelerated from all types of free water surfaces. The water lost in evaporation finds room in an air mass. It adds to the atmospheric vapour storage. Although evaporation loss is excessive in hot season the capacity of the air mass is also more. This large quantity of vapour makes the air mass moist. The change of state from atmospheric vapour to water takes place when the capacity of the air mass to hold the vapour particles exceeds.

Following two main reasons are responsible for this change of state:

i. Hot air mass has large capacity to hold the vapour particles in suspension. When by some means this moist and warm air mass cools down its capacity to hold vapour particles is reduced. Finally vapour precipitates in the form of rainfall.

ii. Sometimes variation in pressure brings about the change of state from vapour to rainfall. It is interesting to know the actual mechanism of precipitation. By a process known as nucleation, ice or water crystals are formed upon the floating particles, in the air mass (e.g., dust particles, salt particles, etc.). The small crystals then grow in the size by combining with other crystals. A stage comes when they fall down on the earth as snow or as rain water.

Forms of Precipitation:

The precipitation takes place in many different forms in the regions located in the middle latitudes.

Typical characteristics of various forms of precipitation are explained below:

(i) Rain:

It consists of water drops mostly larger than 0.5 mm in diameter.

(ii) Drizzle:

They are tiny water droplets of size between 0.1 to 0.5 mm which fall with such slow settling rates that they occasionally appear to float.

(iii) Snow**:**

It is that type of precipitation which results from sublimation, i.e., water vapour directly changes into ice. It falls as white or translucent ice crystals often agglomerated into snowflakes. The specific gravity of snow is often taken to be 0.1.

(iv) Hail:

It is the precipitation in form of lumps of ice. The hail stones are produced in convective clouds mostly cumulonimbus. Their shape may be conical, spheroidal or irregular. The size of hail stones may be anything more than 5 mm. The specific gravity of hail stone is about 0.8.

(v) Snow Pallets:

Sometimes they are called soft hail also. Snow pallets are more crisp and are of size 2 to 5 mm. Due to their, crispness upon hitting the hard ground they often break up.

(vi) Sleet:

When the rain drops fall through the layer of sub-freezing air near the earth's surface the rain drops get frozen to ice stage. It is called sleet or grains of ice.

Types of Rainfall:

Different types of rainfall can be recognised according to the process by which warm and moist air mass gets lifted and subsequently cooled. Broadly speaking there are three types of rainfall.

1. Cyclonic Precipitation or Rainfall:

This type can be sub-divided into:

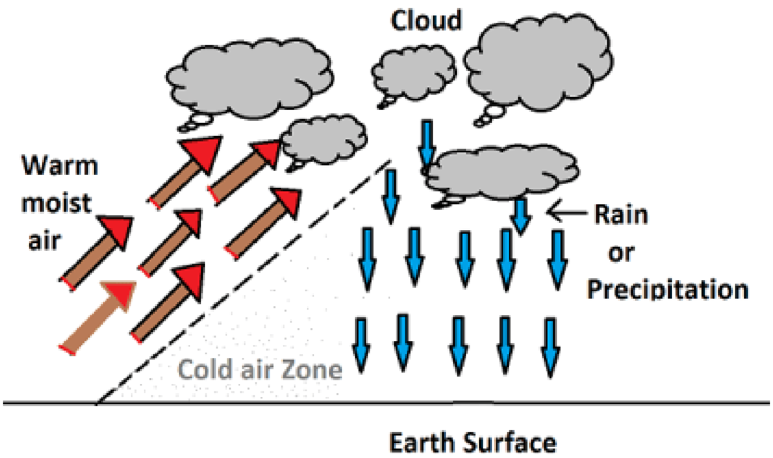
(a) Frontal and

(b) Non-frontal precipitation. This type of rainfall occurs from lifting of air which converges into a low pressure area or cyclone. This type of rainfall generally occurs in plain regions.

(a) Front type of precipitation:

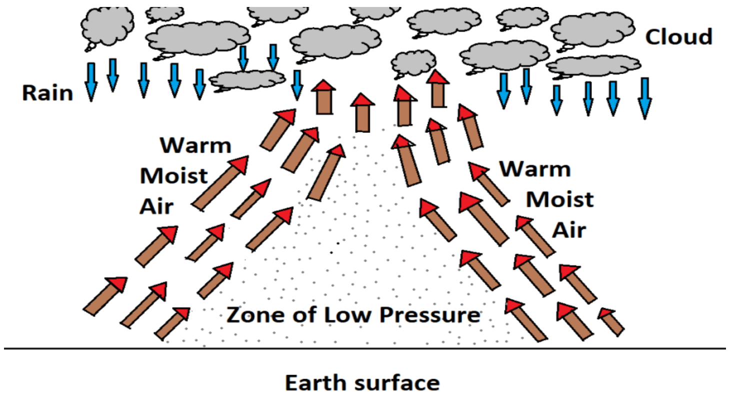
Front is a boundary joining warm moist air mass and cool air mass. When a moving warm moist air mass is obstructed by a stationary cold air mass, the warm air mass rises up as it is lighter than the cold air mass. Sometimes cold moving air mass meets stationary warm air mass with similar results.

The lifted air mass cools down at high altitudes and precipitation occurs. This process continues till the whole warm air mass passes over the cold air mass. A showery type precipitation occurs in case of cold front whereas in case of warm front precipitation continuous rainfall occurs till the warm front passes over the cold air mass.



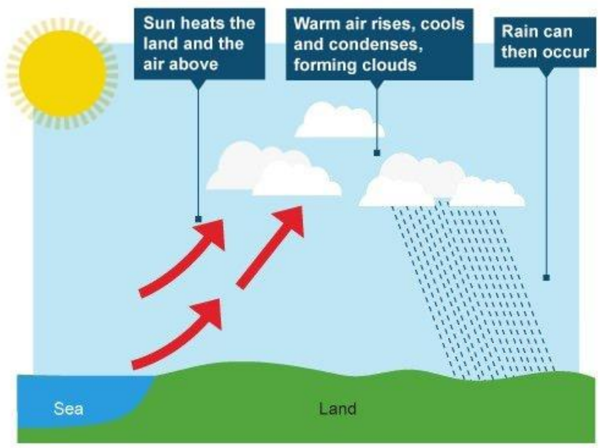
(b) Non-frontal precipitation:

This type of rainfall is not related to fronts. When the moving cold air mass meets the warm moist air mass moist and warm air mass gets lifted up being lighter than the cold air mass. When the warm air mass cools down at high altitude precipitation occurs.



2. Convective Precipitation:

Due to some local effects air gets heated up and stores more vapour particles. Then it rises up in the atmosphere as it is lighter than the cold air surrounding that area. At high altitudes it gets cooled and precipitation occurs. The intensity of this type of precipitation may range from light showers to cloud bursts.



3. Orographic Precipitation:

When a moving warm moist air mass is obstructed by some type of barrier like mountains, the warm moist air mass, finds its way upward and rises to sufficiently high altitudes automatically. There it gets cooled and finally precipitation occurs.
Seaward side mountain slope gets ample rainfall but landward side mountain slope and some portion of the plain receives very little rainfall. The reason for this peculiar phenomenon can be explained as follows. When the elevated warm air mass gets cooled change of state from vapour to water takes place and rainfall occurs on the area below.
Obviously by the time clouds travel past the barrier they get relieved of the moisture and become weak. It takes some time before the clouds regain sufficient moisture to cause precipitation. During this interval the clouds leave some area dry.
The area which does not receive rainfall in this process is called the area of rain-shadow. Figure 2.3 gives lucid illustration of the phenomenon. This area is called the area of rain shadow because one can see the clouds readily passing overhead but the land below does not receive rainfall but only gets shadow of it.

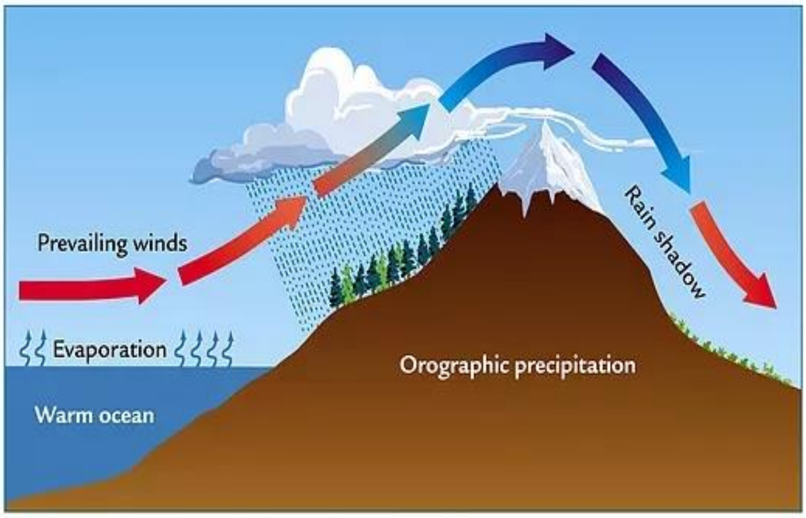


Fig 2.3: Orographic rainfall

Uses of Rainfall Records:

At each rain gauging station the rainfall is measured after 24 hours. Usually the measurement is taken at 0830 hours 1ST obviously total rainfall occurred in the past 24 hours is entered against the date on which measurement is done. The rainfall records are maintained on daily, monthly, seasonally or yearly basis for any basin. The rainfall varies from year-to-year. The average of the series of yearly records gives mean rainfall value. The long term mean is called the normal rainfall.

It is not possible to determine normal rainfall from the rainfall records covering short period. The question now arises is how long should be the rainfall series for obtaining useful results? After the extensive studies Alexander Binnie concluded that the average percentage of deviation from the true mean for 5 years records was ± 15 per cent. For 30 years records it was found to be ± 2 per cent and remained so for longer period also. Thus for obtaining satisfactory results the length of record should be at least for 30 past years.

Following are the main uses of the rainfall records:

1. The trend of rainfall can be studied from rainfall records. Knowing the trend of rainfall future predictions can be done.
2. Runoff over the basin can be calculated.
3. Maximum flood due to any storm can be calculated, and predicted.
4. Rainfall records help in estimating irrigation requirements.

Variation of Rainfall:

Factors responsible for inequitable distribution of rainfall over large area are the following:

1. Nearness to Sea:

From the sea very large quantity of water goes to the atmosphere in the form of vapour. Naturally when excessively moisture laden clouds pass over the sea coast, clouds drop off some of their load. As a result coastal area receives more rainfall.

2. Presence of Mountains:

Windward side slope of the side towards which clouds travel gets excessive rains whereas on the other or leeward side slope there is area of rain-shadow. Mountainous region receives more rainfall than plain areas.

3. Direction of Wind:

Clouds are driven by wind. It is clear that the area over which wind brings clouds will get rainfall.

4. Development of Forest:

The forests also behave to some extent as a barrier and intercept the clouds to derive rainfall. The area with thick forest gets more rainfall.

5. Height of a Place Above Sea Level or Altitude:

The places of high altitude receive more precipitation. At high altitudes temperature of atmosphere is low and when clouds reach that area they get cooled and precipitation occurs.

Hyetograph of Rainfall:

The hyetograph shows the average rainfall rates, over the specified drainage catchment, during successive units of time during a particular storm (Fig. 2.10).

To prepare the hyetograph from given storm, the rainfall quantities during successive units of time are measured from the mass curves of stations in and near the drainage basin. A unit time of 1 to 6 hours as convenient may be selected. The average rainfall depths over the basin for successive units of time are computed from the tabulated data by the Theissen polygon method or isohyetal method. The hyetograph is then drawn by plotting the average rainfall depth per unit of time as shown in Fig. 2.10.
The hyetograph is very convenient in relating the rainfall over the basin with the resulting flood hydrograph. It is usually plotted on the same sheet where hydrograph is plotted. Only thing is it plotted upside down whereas hydrograph is plotted erect (Fig. 2.11).

The hyetograph of a storm when plotted by the side of the flood hydrograph gives the time lag between rainfall and peak flow. It also gives important information about effective duration of storm which produces run-off. The use of hyetograph is commonly made in flood estimation by unit hydrograph method.

10. OCEANIC BOTTOM RELIEF

I welcome you all to this session and here we shall discuss about oceanic bottom relief features, for your convenience this session is divided into 4 major points which are

1. Introduction to oceanography
2. Hypsographic curve
3. Major oceanic relief features
4. Minor oceanic relief features.

Firstly, we will go through the introduction to oceanography

1. Introduction to oceanography

The oceans are one part of the earth system. They mediate processes in the atmosphere by the transfers of mass, momentum, and energy through the sea surface. oceans receive water and dissolved substances from the land. And, oceans lay down sediments that eventually become rocks on land. Hence an understanding of the ocean is important for understanding the earth as a system, especially for understanding important problems such as global change or global warming. At a lower level, physical oceanography and meteorology are merging. The ocean provides the feedback leading to slow changes in the atmosphere.

Definitions of oceanography:

According to **H.A. marmer** "oceanography the science of the sea, includes primarily the study of the form and nature of the oceans basins, the characteristics of the water in these basins and the movement to which these water are subject to".

According to **J. Proudman** "Oceanography studies the fundamental principles of dynamics and thermodynamics in relation to the physical and biological properties of the sea water".

The long history of the study of the ocean has led to the development of various, specialized disciplines each with its own interests and vocabulary. The more important disciplines include:

Oceanography is the study of the ocean, with emphasis on its character as an environment. The goal is to obtain a description sufficiently quantitative to be used for predicting the future with some certainty.

Geophysics is the study of the physics of the earth.

Physical Oceanography is the study of physical properties and dynamics of the ocean. The primary interests are the interaction of the ocean with the atmosphere, the oceanic heat budget, water mass formation, currents, and coastal dynamics. Physical Oceanography is considered by many to be a subdiscipline of geophysics.

Geophysical Fluid Dynamics is the study of the dynamics of fluid motion on scales influenced by the rotation of the earth. Meteorology and oceanography use geophysical fluid dynamics to calculate planetary flow fields.

Hydrography is the preparation of nautical charts, including charts of ocean depths, currents, internal density field of the ocean, and tides.

Earth-system Science is the study of earth as a single system comprising many interacting subsystems including the ocean, atmosphere, cryosphere, and biosphere, and changes in these systems due to human activity.

- Water on earth in liquid form came into presence in Hadean Eon (4,540 – 4,000 mya).
- Throughout the Hadean Eon, temperature on earth was extremely hot, and much of the Earth was molten.
- **Volcanic outgassing** created the primordial atmosphere which consisted of various gases along with water vapour.
- Over time, the planet Earth started to cool, and resulting the formation of a **solid crust**.
- The water vapour condensed to form rain and rainwater gradually filled the depressions on the newly solidified crust.
- The water in the depressions merged to give rise to mighty oceans.
- During the Hadean Eon, the atmospheric pressure was **27 times greater** than it is today and hence even at a surface temperature of close to 200° C water remained liquid in the oceans.
- Over time, both temperature and atmospheric pressure dropped, and water continues to stay as liquid in the oceans.
- The earth, fortunately has an abundant supply of water on its surface. Hence, our planet earth is called as the **'Blue Planet'.**
- **Total surface area of earth: 510 million km^2**
- **Total water surface area: 70.8% (361 million km^2)**
- **Total land surface area: 29.2% (149 million km^2)**

World Oceans by size

Rank	Ocean	Area (million km^2) (%)	Average Depth (m)
1	Pacific Ocean	168 (46.6%)	3,970
2	Atlantic Ocean	85 (23.5%)	3,646
3	Indian Ocean	70 (19.5%)	3,741
4	Antarctic Ocean	21 (6.1%)	3,270
5	Arctic Ocean	15 (4.3%)	1,205

The table on the screen reveals you that the Pacific Ocean is the largest ocean in the world which occupies 46.6 percent of area of the globe (168 million km2), followed by Atlantic Ocean 23.5 percent (85 million km2), Indian ocean 19.5 percent (70 million km2), Antarctic ocean 6.1 percent (21 million km2) and Arctic Ocean 4.3 percent (15 million km2). The deepest ocean in the world is Pacific Ocean with average depth accounting of 3970 m and shallowest ocean is Arctic ocean (average depth is 1205 m).

The following table discloses you the water distribution on the earth

Water on the Earth's surface

Reservoir	Volume (Million Cubic km)	% of the Total
Oceans	1,370	97.25
Icecaps 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

Off the total water on the earth, 97.25 percent of the water on the earth is situated in oceans whereas 2.05 percent is in the form of icecaps and glaciers and remaining water is found in the form of groundwater, lakes, soil moisture, humidity in atmosphere, streams and rivers and biosphere.

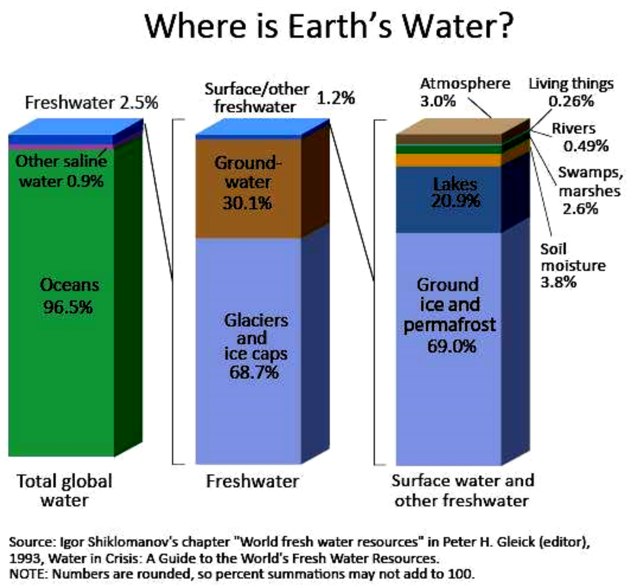


Figure 1.2

Oceanic bottom relief or submarine relief features are mostly resultants of various geomorphic process such as tectonic, volcanic, erosional and depositional and their interactions. Oceanic relief regulates the movement of ocean water. The movement of oceanic water in the form of ocean currents, in turn, leads to several changes in both oceans and atmosphere. Submarine relief of oceans also influences navigation and fishing activities. According to the studies the average depth of the oceans is about 3800 m whereas the average height of the lithosphere is 840 m from the mean sea level. These variations in heights and depth zones of the lithosphere and hydrosphere on the earth planet are represented by a hypsometric curve.

2. Hypsometric Curve

A hypsometric curve, also known as Hypsographic Curve, is a histogram or cumulative distribution function of the earth surface and some part thereof. The variations in hypsometric curves between the landforms arise due to various geomorphic process that alter the landscape may be different.

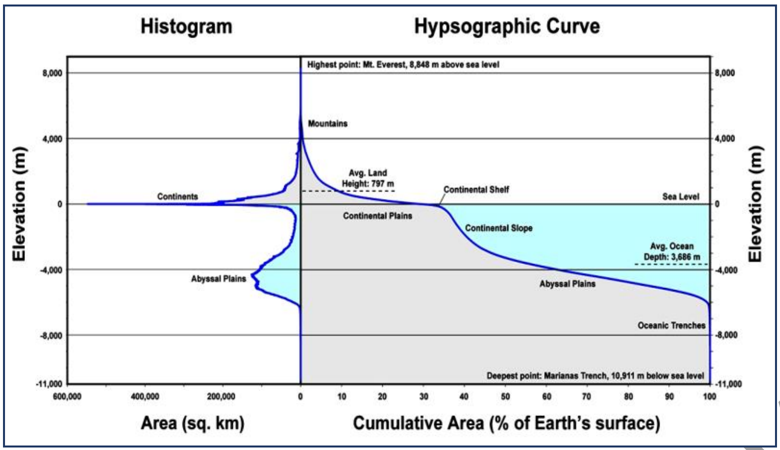
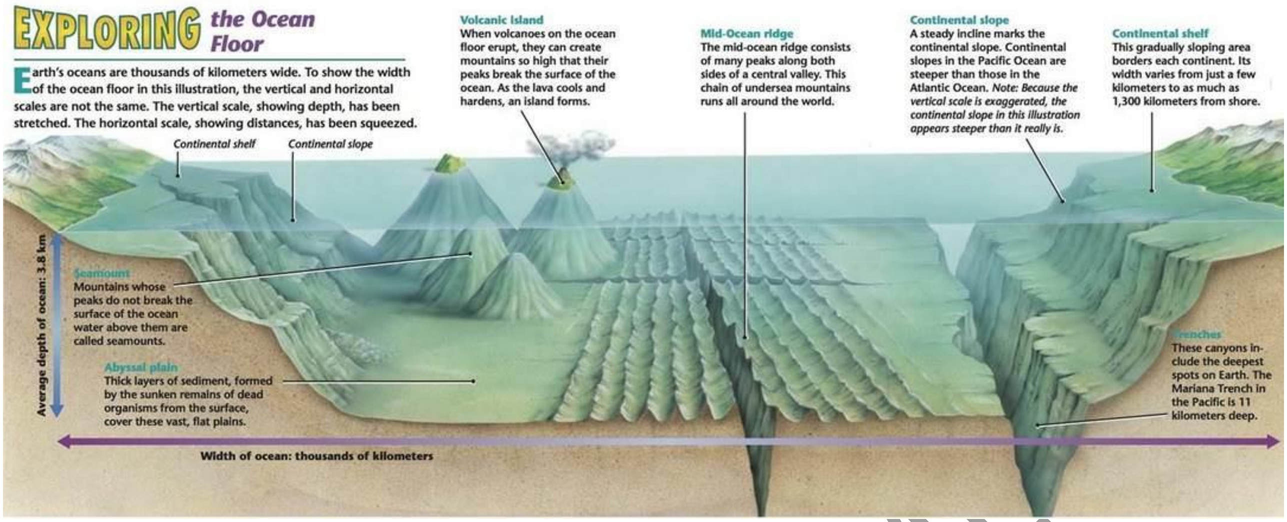


Figure 1.2

When a 2D hypsometric drawn, it discloses the elevation on Y axis (vertical) and area above the corresponding elevations on the X axis (horizontal) (Fig 1.2). The curve can also be display in non-dimensional form by scaling elevation and area by the maximum values. A hypsometric curve is essentially a graph that shows the proportion of landmass that exists at various altitudes by plotting relative area against relative height. In this graphic curve of the whole earth surface there exist two maxima of frequencies; at the 100 m and the 4,700 m elevations, which correlate with the mean level of the lowland continental landmasses and the deep-sea floor. This facet of earth's surface, disclosed by hypsometric analysis, supports the theory of earth crust containing of simatic materials of oceanic crust and of sialic materials of the continental crust.

The histogram (fig 1.2) discloses two primary elevation groupings: the continents, several hundred meters above mean sea level, and the oceanic abyssal plains, roughly 4300 meters blow mean sea level. This geographic distribution shows that the crust of oceanic floor is basically different from the continental crust, which has been confirmed by numerous research studies. The dramatic steepening of the hypsographic curve at mountains and oceanic trenches can only be maintained by a dynamic earth. On geologic timescales, such landscapes would rapidly erode or cover by sediments.

Ocean relief features are divided into major and minor relief features:



Ocean Relief Features

3. Major Ocean Relief Features

Four major divisions in the ocean relief are:

i. the continental shelf,
ii. the continental slope,
iii. the continental rise,
iv. the Deep Sea Plain or the abyssal plain.

i. Continental Shelf

- Continental Shelf is the gently sloping seaward **extension of a continental plate**.
- Gradient of continental shelf is of 1° to 3°.
- These extended margins of all continents are associated with shallow seas and gulfs.
- Continental Shelves of all oceans together consisting **7.5%** of the total area of the oceans.
- The shelf typically ends at a very steep slope, known as **shelf break.**
- The shelves are covered with varying thicknesses of sediments carried down by running water and glacials.
- Examples of continental shelves: Continental Shelf of South-East Asia (Sunda Plate), Grand Banks around Newfoundland, Submerged region between Australia and New Guinea, etc.

Formation

- 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, glaciers**

- There are various types of shelves based on different sediments of terrestrial origin —
    1. **glaciated shelf (e.g. Shelf Surrounding Greenland),**
    2. **coral reef shelf (e.g. Queensland, Australia),**
    3. **shelf of a large river (e.g. Shelf around Nile Delta),**
    4. **shelf with dendritic valleys (e.g. shelf at the Mouth of Hudson River)**
    5. **shelf along young mountain ranges (e.g. Shelves between Hawaiian Islands).**

Various types of shelves

Width and depth of continental shelves

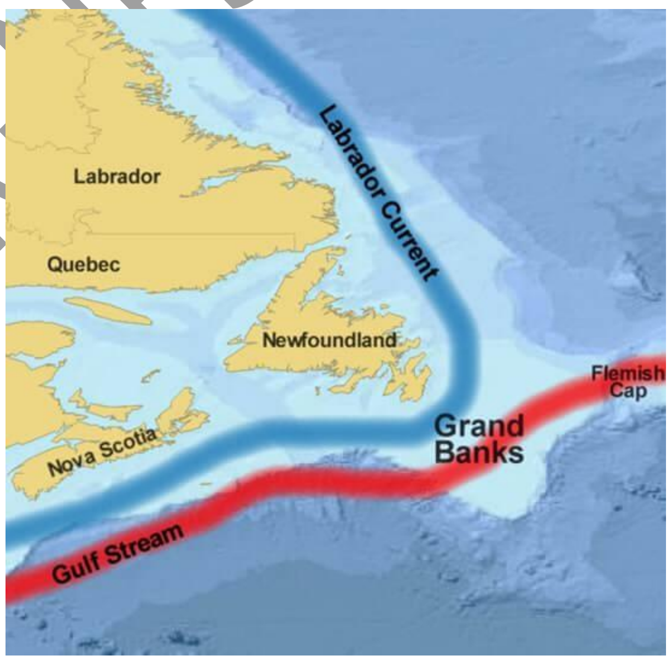
- Continental shelves have an average width of **70-80 km.**
- The shelves are almost absent or very narrow along a convergent boundary. E.g. coasts of Chile.
- The width of continental shelf of eastern coast of USA varies between 100-300 km.
- **Siberian shelf** in the Arctic Ocean is the largest in the world and stretches up to 1,500 km from the coast.

Width of various continental shelves

- Continental shelves may be as shallow as 30 m in some areas while in some areas it is as deep as 600 m.

Importance of continental shelves

- 20% of the world production of **petroleum** and gas comes from shelves.
- Continental shelves form the richest fishing grounds. E.g. Grand Banks around Newfoundland.



Grand Banks, the richest fishing grounds on earth

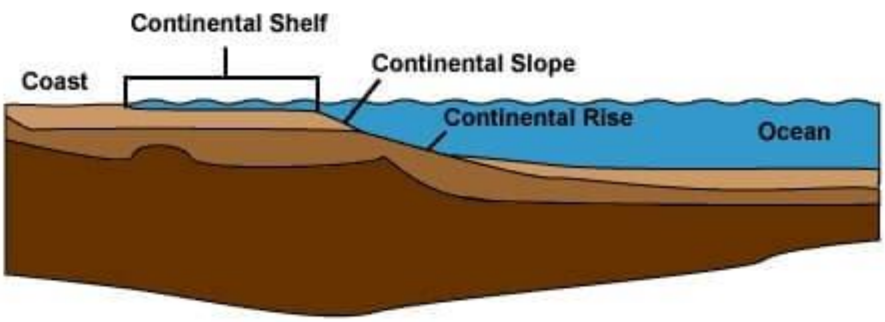
- Marine food comes almost entirely from continental shelves.
- They are sites for **placer deposits** and **phosphorites** (explained in Ocean Resources).

ii. Continental Slope

- The gradient of the slope region varies between **2-5°.**
- The continental slope connects the continental shelf and the ocean basins.
- 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.

iii. 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.**



Shelf, Slope and Rise (Wikipedia)

iv. 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** (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.

4. Minor Ocean Relief Features

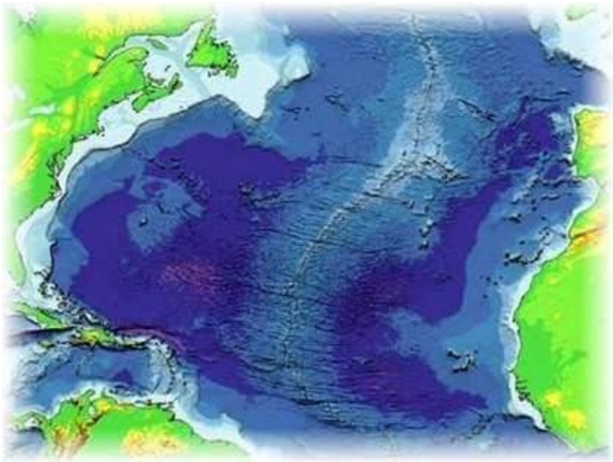
- Ridges (along a divergent boundary),
- Abyssal Hills (submerged volcanic mountains): Seamounts and Guyots,
- Trenches (along a convergent boundary),
- Canyons (erosional landform),
- Island arcs (formed due to volcanism along a convergent boundary or hotspot volcanism),
- Atolls and Coral reefs.

i. 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.**
- Trenches are associated with **active volcanoes** and **strong earthquakes** (like in Japan).
- Majority of the trenches are in the Pacific Ocean followed by the Atlantic Ocean and Indian Ocean.

ii. Mid-Oceanic Ridges or Submarine Ridges

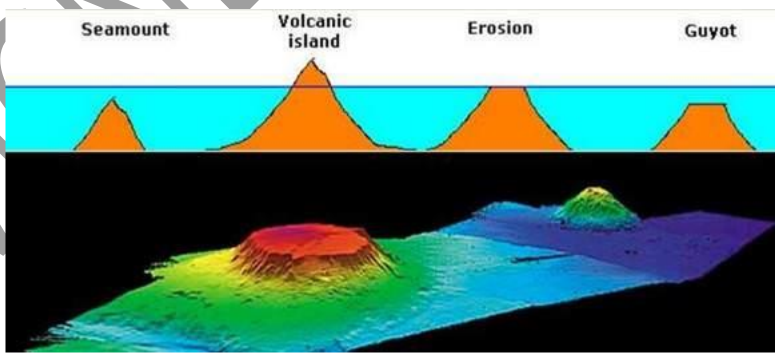
- A mid-oceanic ridge is composed of two chains of mountains separated by a large depression (divergent boundary).
- The mountain ranges can have peaks as high as 2,500 m and some even reach above the ocean's surface.
- Running for a total length of **75,000 km**, these ridges form the **largest mountain systems on earth.**



Mid Ocean Ridge

- The ridges are either broad, like a plateau, gently sloping or in the form of steep-sided narrow mountains.

iii. Abyssal Hills



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.

iv. 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 typically with a river or stream flowing through it.

Canyon, George, Valley

- Submarine canyons are deep valleys often extending from the mouths of the rivers to the abyssal plains.
- They are formed due to erosion by sediments brought down by rivers that cut across continental shelves, slopes and rises. The sediments are deposited on the abyssal plains.
- Submarine canyons can be far higher in scale compared to those that occur on land.

Submarine Canyon

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 **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.

v. 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.

Atoll

vi. 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.

1. 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 examples.
- **The banks are sites of some of the most productive fisheries of the world.**

2. Shoal

- A shoal is a detached elevation with shallow depths.
- Since they project out of water with moderate heights, they are **dangerous for navigation.**

Shoal

3. 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**.
- Since the reefs may extend above the surface, they are generally **dangerous for navigation.**

Reef

MAJOR OCEANS AND SEAS

b. Oceans of the World by Size

Rank	Ocean	Area (million km²) (%)	Average Depth (m)
1	Pacific Ocean	168 (46.6%)	3,970
2	Atlantic Ocean	85 (23.5%)	3,646
3	Indian Ocean	70 (19.5%)	3,741
4	Antarctic Ocean	21 (6.1%)	3,270
5	Arctic Ocean	15 (4.3%)	1,205

- **Total surface area of earth: 510 million km^2**
- **Total water surface area: 70.8% (361 million km^2)**
- **Total land surface area: 29.2% (149 million km^2)**

c. 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.

1. 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** (E.g. Hawaiian Hotspot).

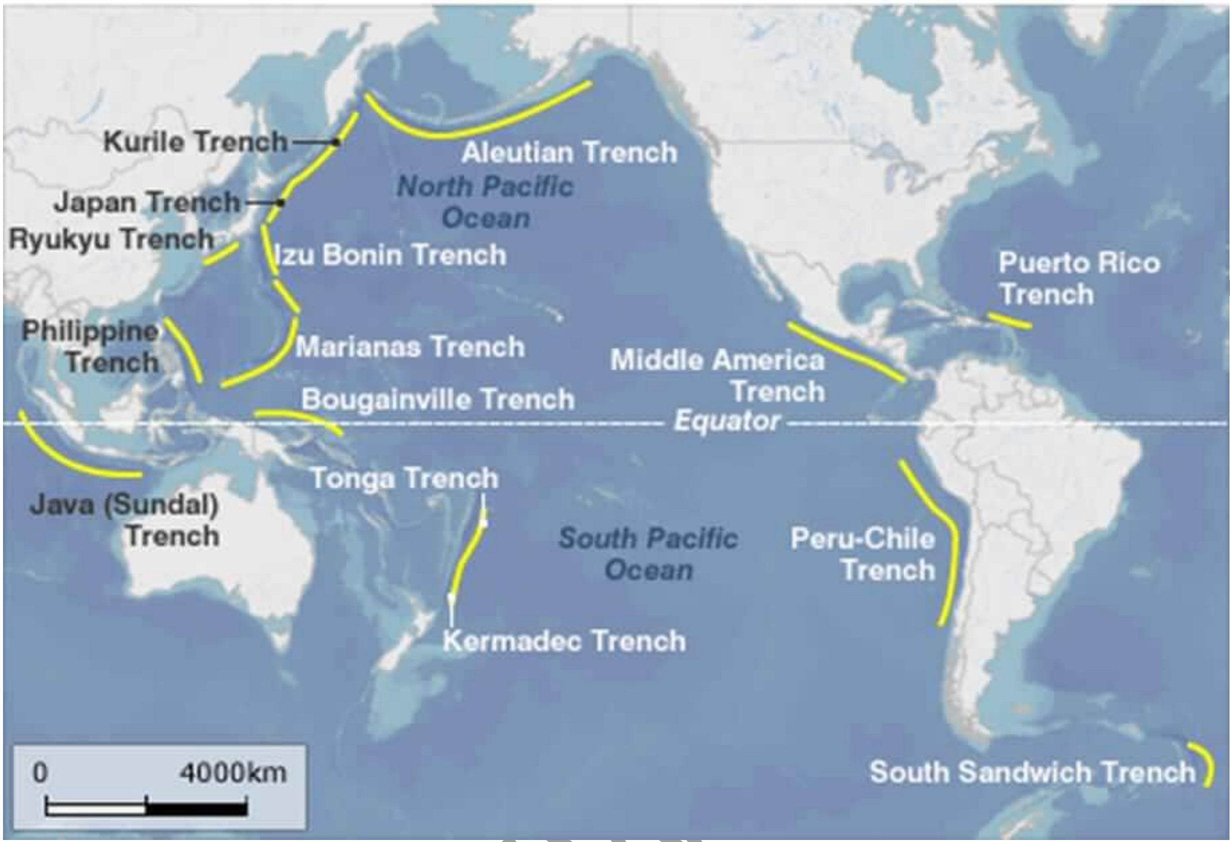
2. West and South-West Pacific

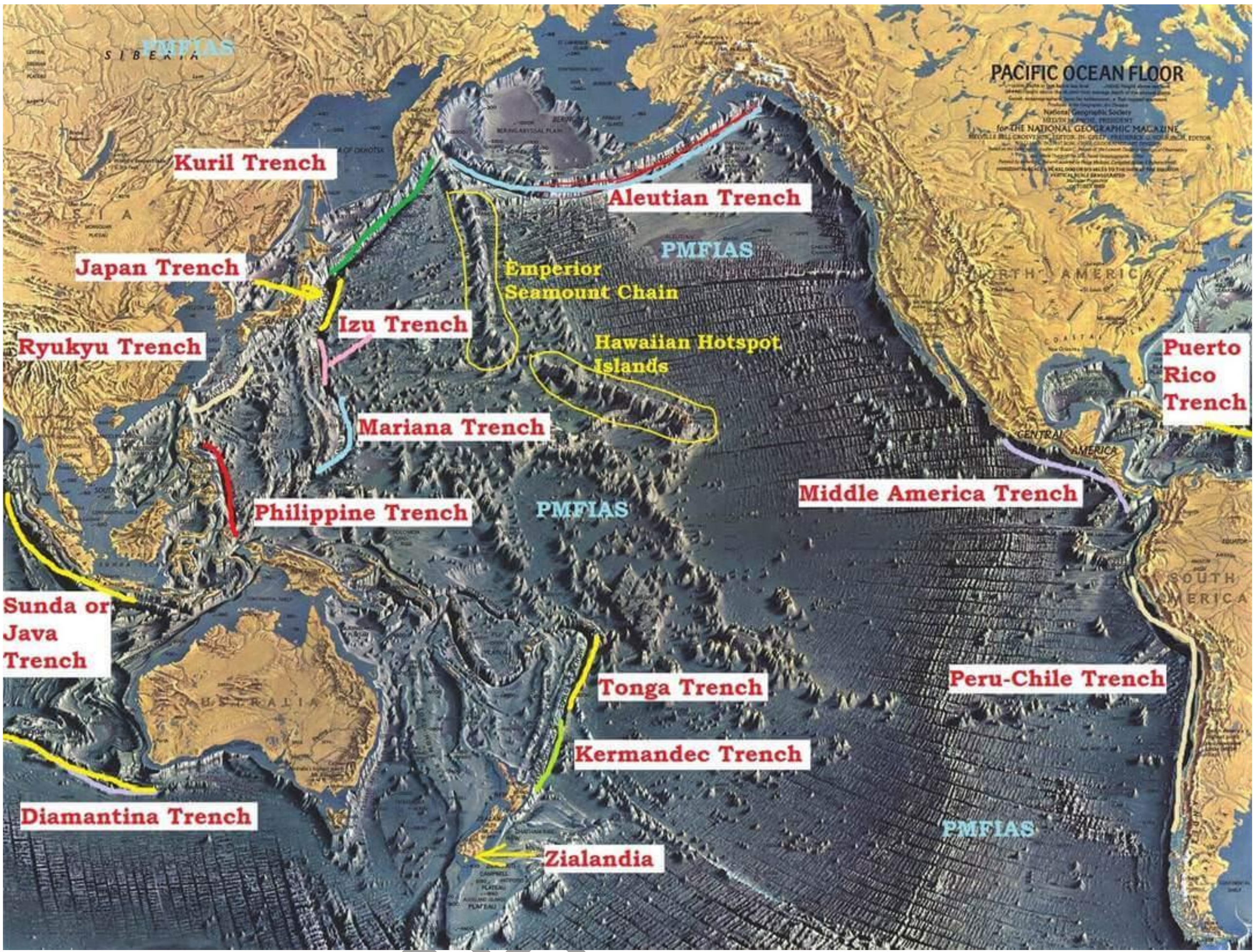
- Average depth is about **4,000 m.**
- It is marked by a variety of islands, marginal seas, continental shelves and submarine trenches.
- **Mariana Trench** and **Mindanao Trench** are very deep with a depth of more than 10,000 metres.

3. 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





Pacific Ocean Topography (Exaggerated) showing trenches and spreading sites

d. The Atlantic Ocean

- The Atlantic is the **second largest** ocean after the Pacific.
- It is roughly **half** the size of the Pacific Ocean.
- Its shape resembles the letter '**S**'.
- In terms of **trade**, it is the most significant of all oceans.

1. 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.


ATLANTIC OCEAN FLOOR
GREENLAND
ICELAND
PMFIAS
NORTH AMERICA
EUROPE
Bermuda
Canary Islands
Cape Verde Islands
AFRICA
Puerto Rico Trench
SOUTH AMERICA
PMFIAS
Falkland Island [Overseas Territory of Britain]
South Sandwitch Trench

Atlantic Ocean Topography (Exaggerated) showing trenches and spreading sites

- **Grand banks continental shelf is the most productive continental shelf in the world**.
- 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).

2. 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.**

3. Seamounts and guyots

- They are present in significant numbers but not as significant as in Pacific Ocean.
- Several seamounts form islands of the mid-Atlantic. Examples include **Pico Island of Azores, Cape Verde Islands, Canary Islands etc.**
- Also, there are coral islands like **Bermuda** and volcanic islands like **St Helena** etc.

4. 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.

e. The Indian Ocean

- Indian Ocean is the third largest of the world's oceanic divisions.
- Smaller and less deep than the Atlantic Ocean.

1. Submarine ridges

- Submarine ridges in this ocean include the **Lakshadweep-Chagos Ridge (Reunion Hotspot Volcanism)**, 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.


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 metr
ASIA
AFRICA
AUSTRALIA
INDIAN OCEAN
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
Yangtze
Irrawaddy
Kolkata
Chittagong
Salween
Mekong
Nile
RED SEA
Jiddah
Port Sudan
Gulf of Oman
OMAN BASIN
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
Maldives
Colombo
Sri Lanka
Nicobar Is.
–5,826
CARLSBERG RIDGE
CHAGOS-LACCADIVE PLATEAU
–2,764
Singapore
PACIFIC OCEAN
SOMALI BASIN
Sumatra
Borneo
Seychelles
Amirante Islands
Chagos Archipelago
CHAGOS TRENCH
COCOS BASIN
Sunda Strait
Celebes
JAVA SEA
New Guinea
Dar es Salaam
MASCARENE PLATEAU
VEMA TRENCH
MID-INDIAN BASIN
NINETYEAST RIDGE
JAVA TRENCH
–6,250
Java
Lesser Sunda Islands
Comoros
MASCARENE BASIN
Christmas Island
NORTH AUSTRALIAN BASIN
TIMOR SEA
Darwin
Zambezi
Madagascar
–1,737
Cocos Islands
EXMOUTH PLATEAU
Cape Londonderry
Mozambique Channel
Le Port
Port Louis
Réunion
WHARTON BASIN
Port Hedland
MOZAMBIQUE BASIN
Orange
MOZAMBIQUE PLATEAU
–5,883
MADAGASCAR BASIN
MID-INDIAN RIDGE
Durban
BROKEN RIDGE
PERTH BASIN
Fremantle
Darling
Cape of Good Hope
MADAGASCAR PLATEAU
DIAMANTINA FRACTURE ZONE
Great Australian Bight
Adelaide
Cape Agulhas
Amsterdam Island
St. Paul Island
Melbourne
ATLANTIC OCEAN
AGULHAS PLATEAU
SOUTHWEST INDIAN RIDGE
CROZET BASIN
SOUTHEAST INDIAN RIDGE
SOUTH AUSTRALIAN BASIN
–5,671
Bass Strait
Tasmania
AGULHAS BASIN
DEL CAÑO RISE
Crozet Islands
Kerguelen Islands
SOUTH TASMAN RISE
ATLANTIC-INDIAN RIDGE
CONRAD RISE
Kohler Seamount
KERGUELEN PLATEAU
Williams Seamount
SOUTHEAST INDIAN RIDGE
ENDERBY ABYSSAL PLAIN
AUSTRALIAN-ANTARCTIC BASIN
30°
60°
90°
120°
0
750
1000
Scale is true only on the Equa
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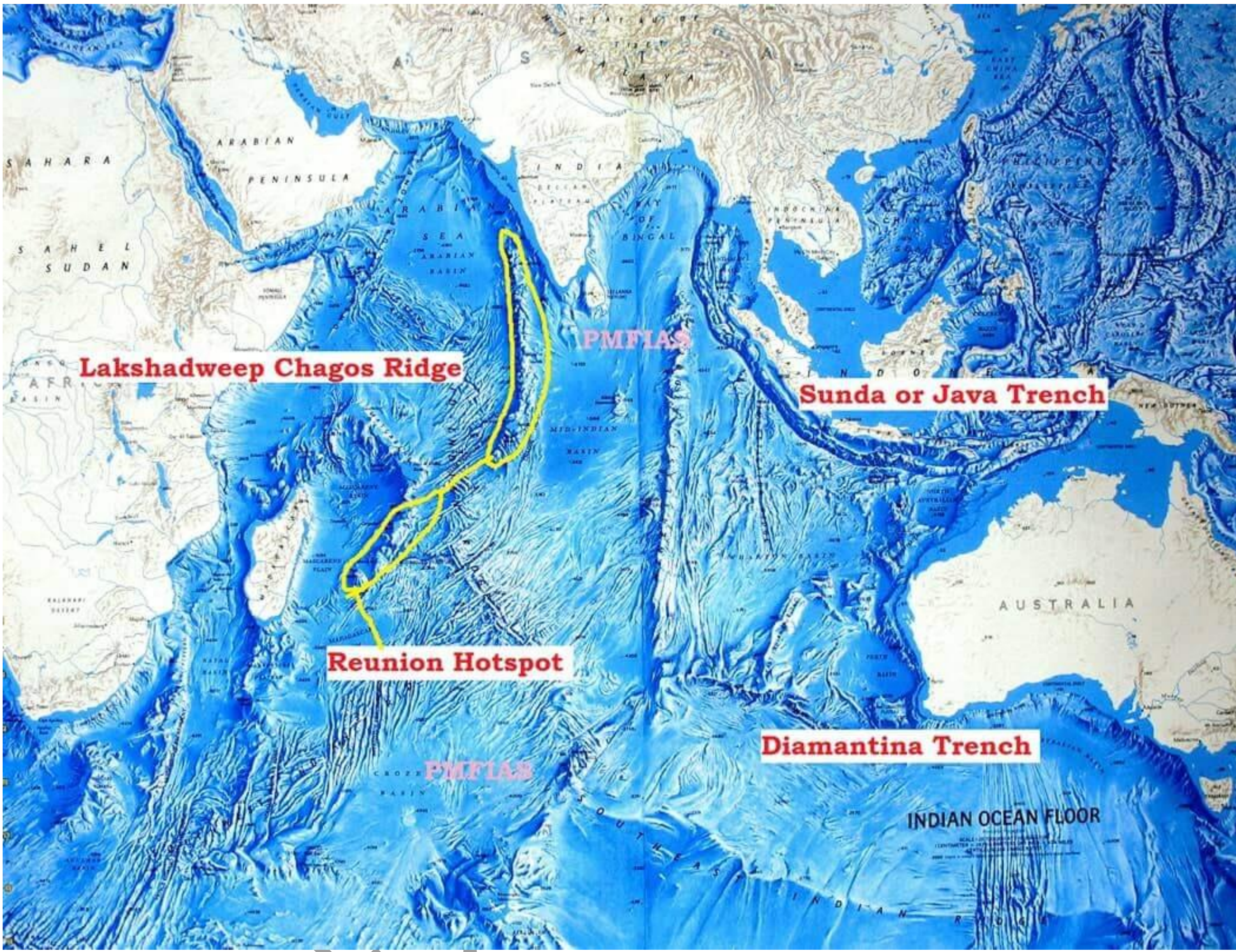


Indian Ocean Topography (Exaggerated) showing trenches and spreading sites

2. 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.

3. 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).

4. 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.

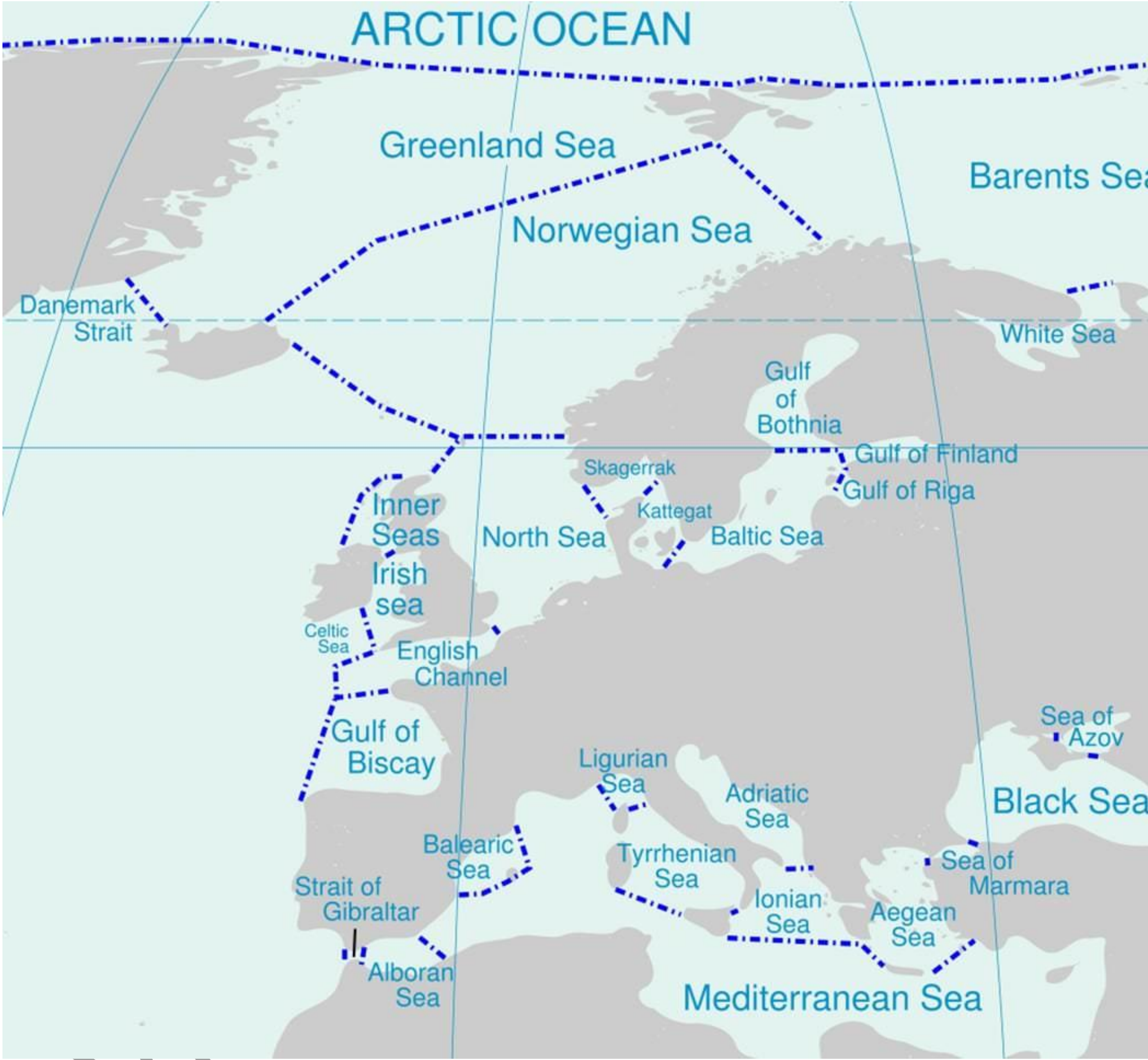
5. Straits

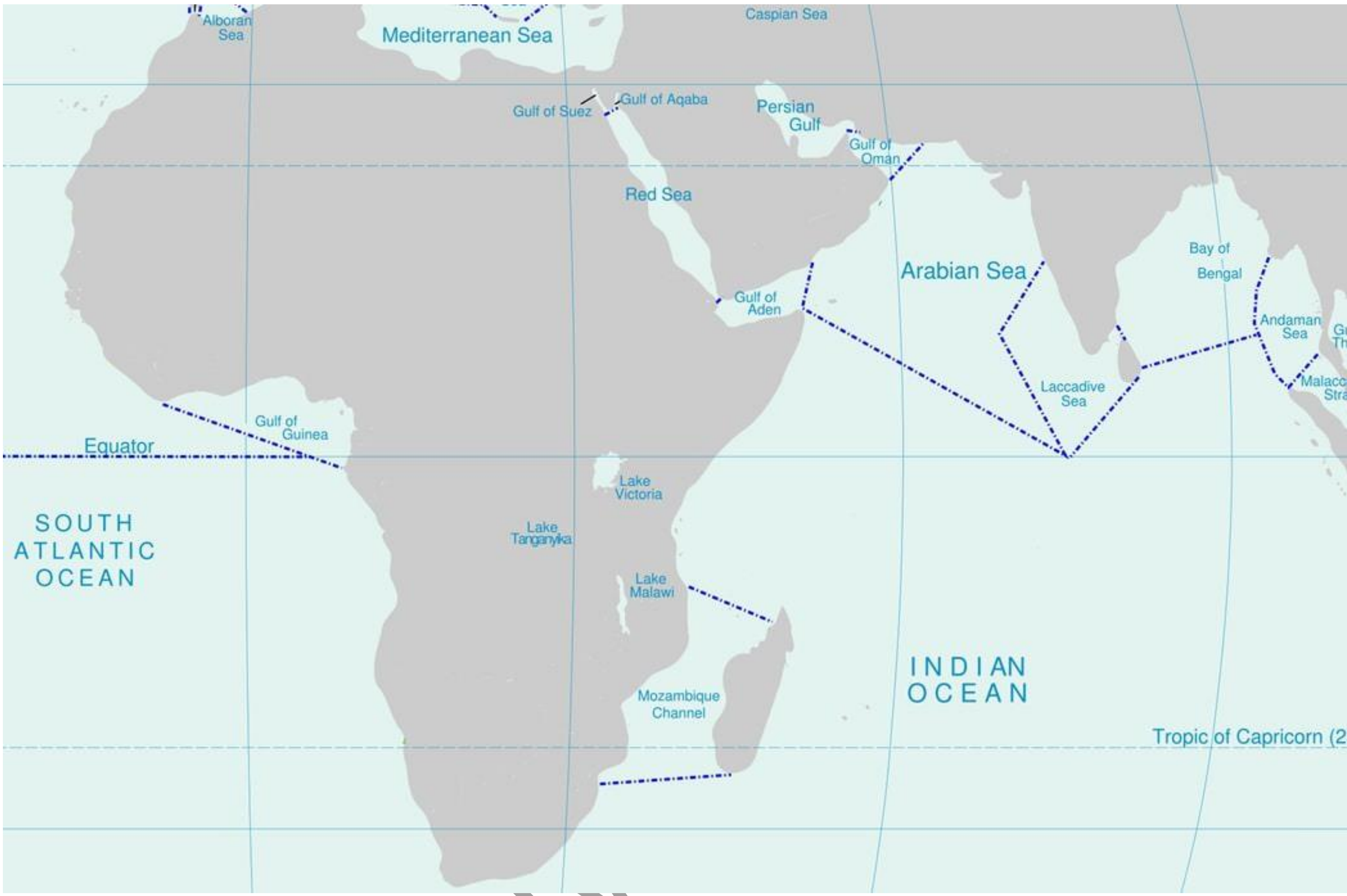
- Most of the straits in Indian Ocean are important trade roots.
- The major chokepoints include **Bab el Mandeb (between Yemen and Djibouti, Eritrea), Strait of Hormuz (separates Persian Gulf from the Gulf of Oman)**, the **Lombok Strait (connects Java Sea to the Indian Ocean)**, the **Strait of Malacca (between Malay peninsula and Sumatra Island)** and the Palk Strait.

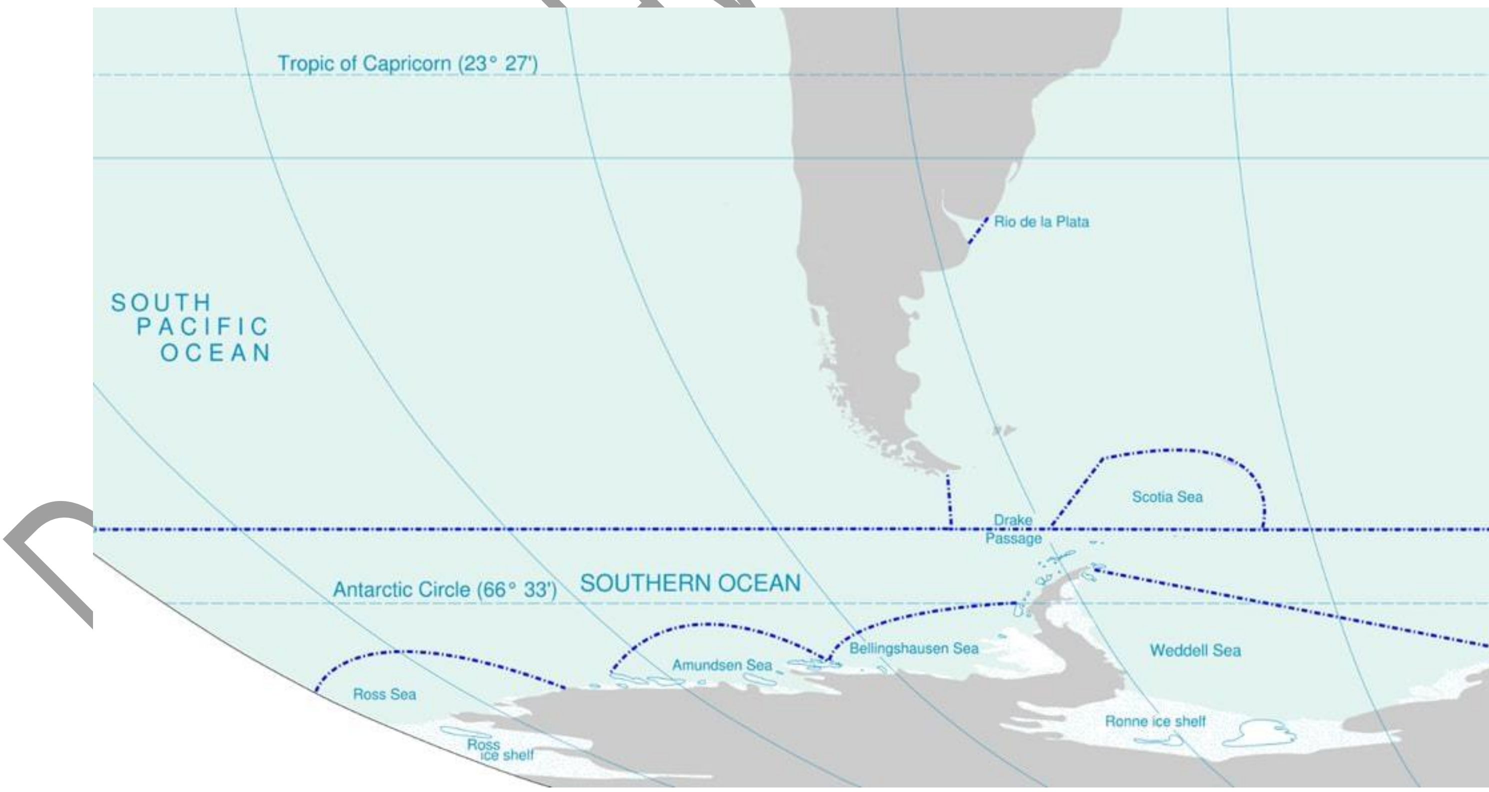
f. Marginal Seas

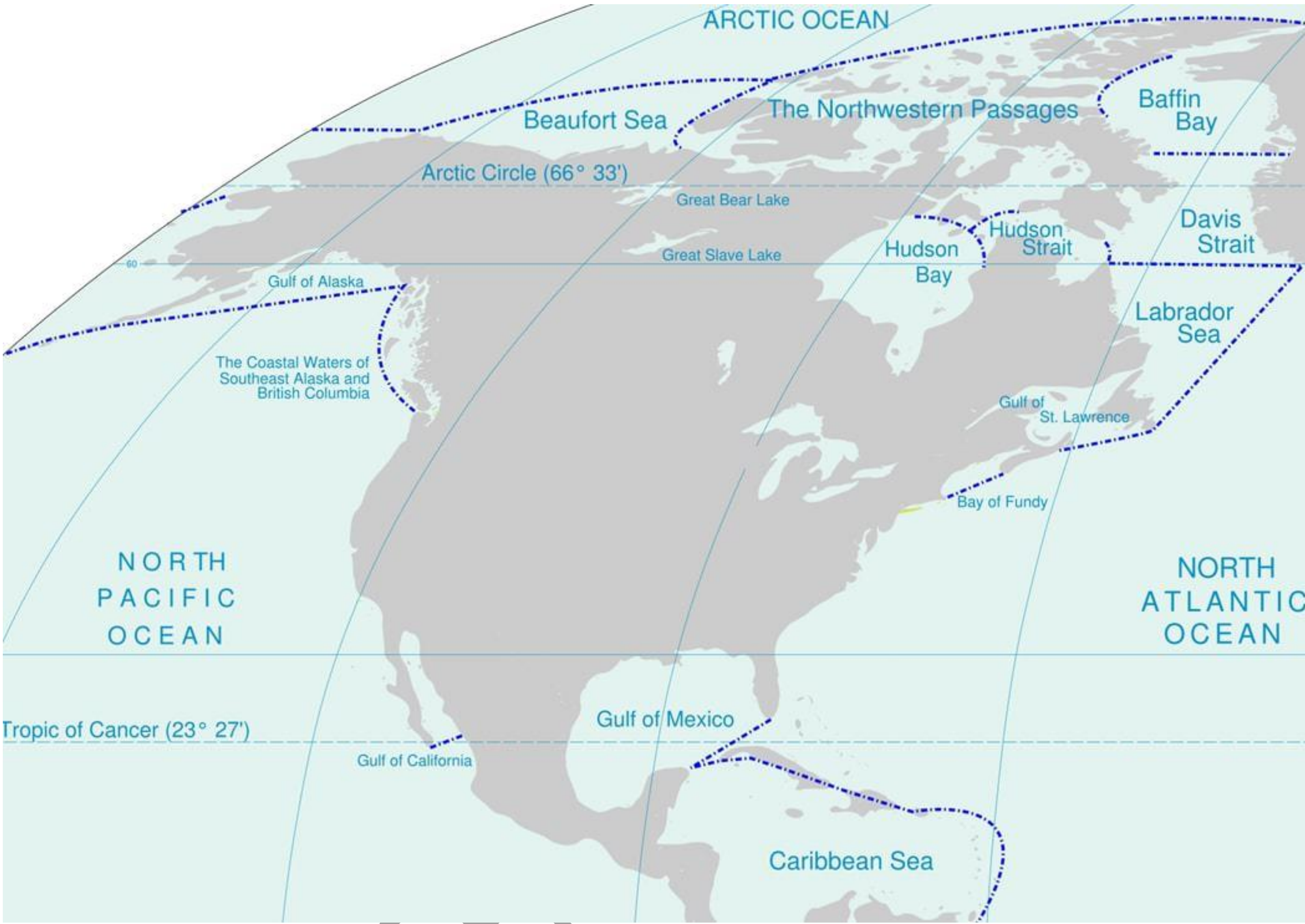
- In oceanography, a marginal sea is a sea **partially enclosed** by islands, archipelagos, or peninsulas.
- Some of the major marginal seas include the **Arabian Sea, Baltic Sea, Bay of Bengal, Bering Sea, Black Sea, Gulf of California, Gulf of Mexico, Mediterranean Sea, Red Sea,** and all four of the **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.

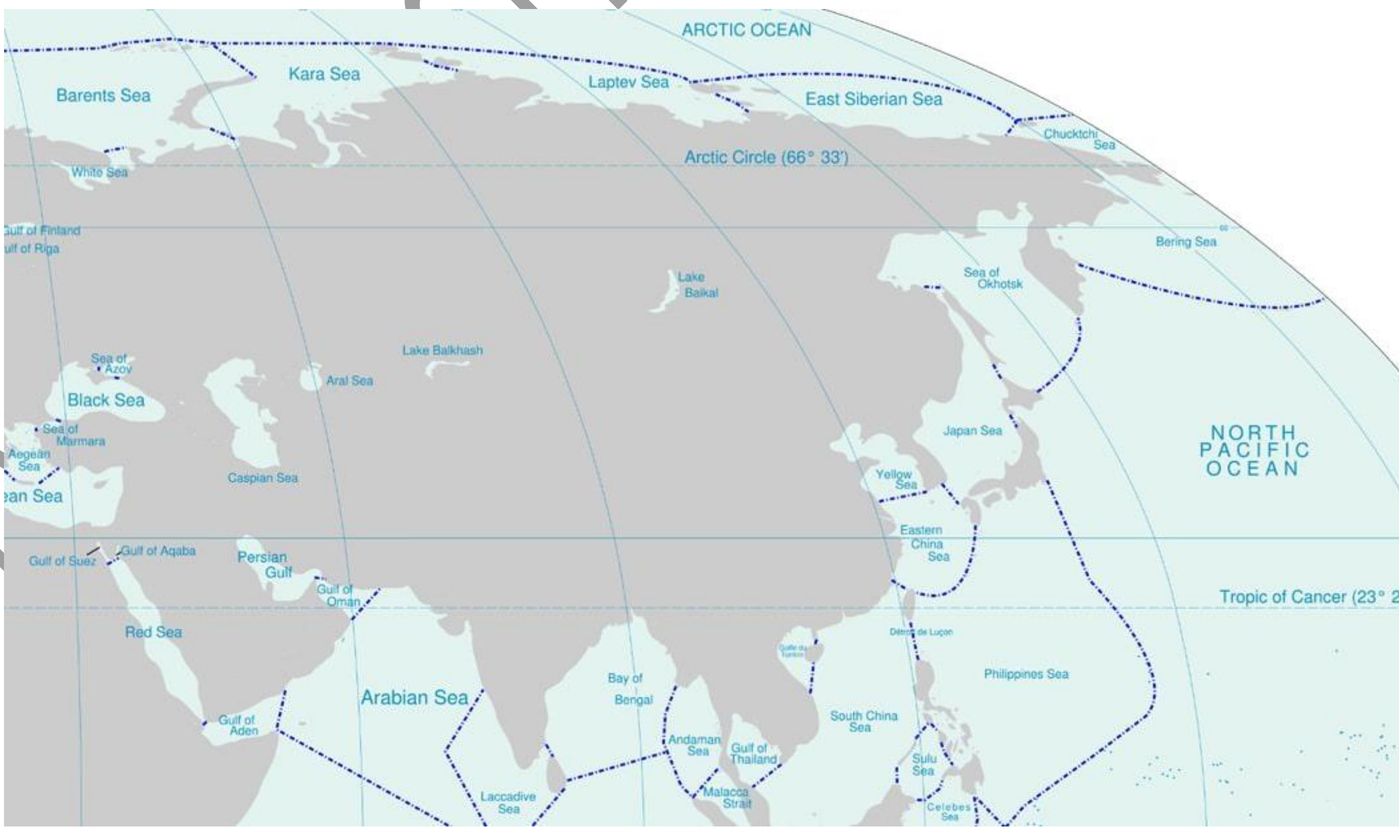
Marginal Seas map: ***https://drive.google.com/file/d/0B1myJlOn-mMCNWJYSWtMZTltVGM/view?usp=sharing***

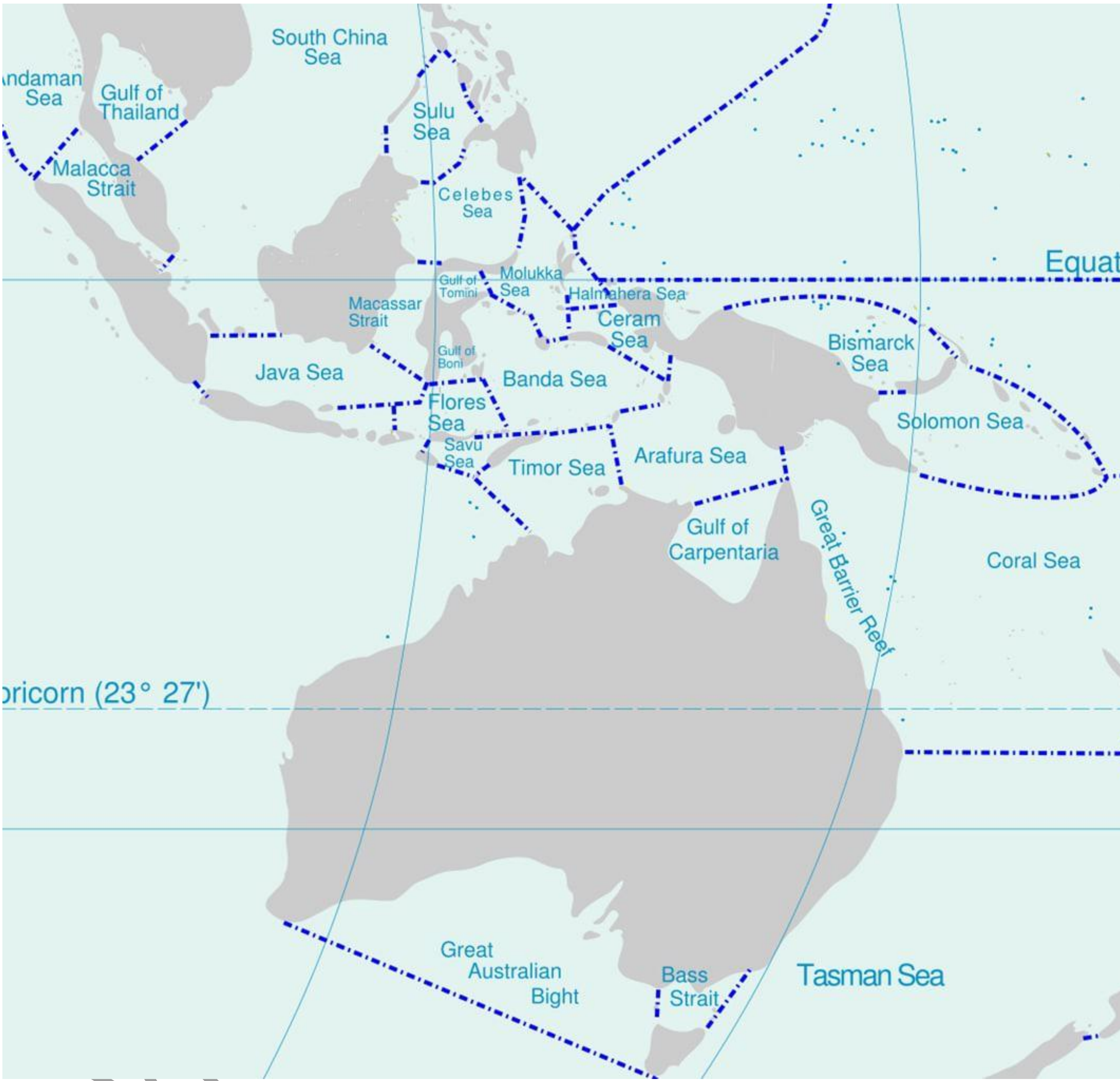

ARCTIC OCEAN
Greenland Sea
Barents Sea
Norwegian Sea
Danemark Strait
White Sea
Gulf of Bothnia
Gulf of Finland
Gulf of Riga
Skagerrak
Kattegat
Baltic Sea
Inner Seas
North Sea
Irish sea
Celtic Sea
English Channel
Gulf of Biscay
Ligurian Sea
Adriatic Sea
Sea of Azov
Black Sea
Balearic Sea
Tyrrhenian Sea
Sea of Marmara
Strait of Gibraltar
Ionian Sea
Aegean Sea
Alboran Sea
Mediterranean Sea


Alboran Sea
Mediterranean Sea
Caspian Sea
Gulf of Suez
Gulf of Aqaba
Persian Gulf
Gulf of Oman
Red Sea
Arabian Sea
Bay of Bengal
Gulf of Aden
Andaman Sea
Laccadive Sea
Gulf of Guinea
Equator
Lake Victoria
SOUTH ATLANTIC OCEAN
Lake Tanganyika
Lake Malawi
INDIAN OCEAN
Mozambique Channel


Tropic of Capricorn (23° 27')
Rio de la Plata
SOUTH PACIFIC OCEAN
Scotia Sea
Drake Passage
Antarctic Circle (66° 33')
SOUTHERN OCEAN
Bellingshausen Sea
Weddell Sea
Amundsen Sea
Ross Sea
Ross ice shelf
Ronne ice shelf


ARCTIC OCEAN
Beaufort Sea
The Northwestern Passages
Baffin Bay
Arctic Circle (66° 33')
Great Bear Lake
Hudson Strait
Davis Strait
Great Slave Lake
Hudson Bay
Gulf of Alaska
Labrador Sea
The Coastal Waters of Southeast Alaska and British Columbia
Gulf of St. Lawrence
Bay of Fundy
NORTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
Gulf of Mexico
Tropic of Cancer (23° 27')
Gulf of California
Caribbean Sea


ARCTIC OCEAN
Kara Sea
Barents Sea
Laptev Sea
East Siberian Sea
Chucktchi Sea
White Sea
Arctic Circle (66° 33')
Gulf of Finland
Gulf of Riga
Bering Sea
Sea of Okhotsk
Lake Baikal
Sea of Azov
Lake Balkhash
Aral Sea
Black Sea
Sea of Marmara
Aegean Sea
Japan Sea
NORTH PACIFIC OCEAN
Caspian Sea
Yellow Sea
Eastern China Sea
Gulf of Suez
Gulf of Aqaba
Persian Gulf
Gulf of Oman
Tropic of Cancer (23°
Red Sea
Philippines Sea
Bay of Bengal
Arabian Sea
South China Sea
Gulf of Aden
Andaman Sea
Gulf of Thailand
Sulu Sea
Laccadive Sea
Malacca Strait
Celebes Sea



Major Marginal Seas

i. Human Impact on marginal seas

- Marginal seas are **more susceptible to pollution** than open ocean regions.
- The greatest human impact on marginal seas is related to the **fisheries industry**.
- 90% of the world's fisheries exist within coastal waters that are located less than 200 km from the shoreline.

- Other human activities that have adversely affected marginal seas include industrial sewage disposal, offshore oil drilling, accidental releases of pollutants, radioactive waste, etc.
- Pollutants from the nearby landmasses are introduced into marginal seas in concentrations that are thousands of times greater than in open oceans.

1. Phytoplankton Bloom (Algal Bloom) in Marginal Seas

- The Mediterranean Sea and the Black Sea are marginal seas found in proximity to one another. The colors difference is due to a **phytoplankton bloom** occurring in the Black Sea.

Phytoplankton bloom 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.

ii. 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**.
- For nearshore regions, the dominant processes influencing primary productivity are river runoff, water column mixing, and **turbidity.**
- River runoff and water column mixing introduce dissolved nutrients and trace elements into the photic (light) zones of nearshore regions.
- Although the addition of dissolved nutrients and trace elements serve to increase primary production, the addition of suspended particles increases water **turbidity**, which results in reduced sunlight penetration and **decreased** primary productivity.

iii. 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:

1. 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**.

2. 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 **humanmade 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.

3. Gulf of Mexico

- 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.

g. 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 neighbours are common.

i. 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).**

1. 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 harbour 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 infamous **Guantánamo Bay prison** is here.

ii. 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.

iii. 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 north-western Turkey.

- The Strait of Hormuz is located at the **south-eastern 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.

1. 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).

iv. 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**.

Isthmus of Panama and Isthmus of Suez

Module 11: Temperature Distribution of Oceans

I welcome you all to this session and here we shall discuss about temperature of the oceans, for your convenience this session is divided into 5 major points which are

1. **Introduction**
2. **Sources of heat in oceans**

3. **Annual range of ocean temperature**
4. **Horizontal distribution of ocean temperature**
5. **Vertical distribution of ocean temperature**

1. Introduction

The study of ocean temperature is the subject matter of marine meteorology which deals with that portion of the atmosphere and its interaction with the ocean which overspreads the great water masses. The study of the temperature of the oceans is very important for determining the following:

1. Movements and characteristics of large volumes of oceanic water (vertical and horizontal ocean currents),
2. classification and spatial distribution of marine organisms including plants and animals at various depths of oceans,
3. effects of climate of coastal lands and plants and animals therein etc.

Temperatures of ocean surfaces have a large-scale impact on weather and climate. For instance, a wide swath of the Pacific Ocean along the equator warms up 2 to 3 degrees Celsius for every 3 – 7 years. This event is a hallmark of the climate pattern El Nino, which alters global patterns of rainfall, triggering heavy rainfall in the southern USA and spartan drought in southern Asia, Indonesia and Australia. On a smaller scale, ocean temperature also influences the advance of tropical cyclones (hurricanes and typhoons), which draw energy from warm ocean water to origin and intensify.

There are three types of instruments useful for recording ocean temperature, viz:

i. Standard type thermometers: they are used to measure the temperatures of ocean surfaces
ii. The reversing thermometers: they help us to measure sub-surface temperature of oceans.
iii. The Thermographs

All these thermometers are used to record the ocean temperature up to the accuracy of ± 0.02° C with respect to temperature. Recently, the automatic self-recording thermometers are also available to measure the ocean temperature instead of above mentioned three thermometers.

2. Sources of Heat in Oceans

Ocean waters get heated up by the solar energy just as land masses. The process of heating and cooling of the oceanic water is slower than land. The sun is the principal source of energy (Insolation). Besides, the ocean water is also heated by the inner heat of the ocean itself (at the ocean bottom, the crust is only about 5 to 30 km thick). But this heat is negligible compared to that received from sun.

2.1 The ocean water is heated by the following three processes

- **Absorption of sun's radiation:** it is maximum over low latitudes due to vertical insolation and longer duration of daylight, whereas it decreases steadily towards poles. Even within the same latitude, the solar insolation received by the sea varies due to factors such as currents and cloudiness.
- **The conventional currents:** the convectional currents in the water bodies also heat up the oceanic water. Since, the temperature of the earth increases with increasing depth, the ocean water at great depths is heated rapidly than the subsurface and intermediate water layers. So, a convectional oceanic circulation at the bottom layers of oceans takes place causing circulation of heat in water.
- **Kinetic energy:** Heat is produced due to friction caused by the surface winds and the tidal currents which increase stress on the water body. Thus, the oceanic water gets heated up.

2.2 The ocean water is cooled by following processes

1. **Back radiation:** Back radiation from the ocean surface takes place as the solar energy once received is re-radiated as long wave radiation form the seawater.
2. **Exchange of heat:** exchange of heat between the sea and the atmosphere takes place, but only if there is temperature difference.
3. **Evaporation:** it takes place when ocean water is warm, surface is cold and atmospheric stratification is unstable. Heat is lost in the form of latent heat of evaporation (atmosphere gains this heat in the form of latent heat of condensation).

3. Heat Balance of the Oceans

The heat budget or heat balance of oceans consists of inputs and outputs. "Input" identifies a process through which the ocean gains heat, while "output" represents a heat loss to the ocean. In simple words, Heat balance, in general, indicates that the total supply in energy is balanced by the loss of equal amount of energy. The heat balance of oceans is primarily controlled by various processes of heating of the ocean water and the various processes of cooling of the ocean waters as mentioned earlier. **Mosby** viewed that the average annual surplus of insolation between the equator and 10° N latitude was about 0.170 grams calories/cm2/minute, while it is about 0.040 grams calories/cm2/minute between 60° N and 70° N latitudes. This difference of surplus of insolation completely disappears if we take all the latitudinal regions into consideration. **Defant** has computed the details of heat budget of the oceans. By taking into consideration all the important processes of incoming and outgoing heat, he has calculated gains and losses for various latitudes, i.e., from equator to 20° N & S there is net gain, whereas further poleward the amount of losses gradually increases.

According to the nature of heat distribution, the oceans exercise a thermostatic control on climate through the surplus of incoming radiation. The water surface reflects a little amount of solar radiation while the major part absorbed in the sea water and given off to the atmosphere during periods when the air is colder than the sea surface. Further, this surplus radiation from the sun and sky is minimized to zero by the evaporation from the sea surface and the sensitive heat transfer from the sea to the atmosphere.

Table 1: Composition of Sea Temperature (Daily per cm^2/grams calories)

S. No Latitudes	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
1. Absorbed directly from sun	202	255	267	233	171	107	80	58	44	39
2. Absorbed through dispersion	166	129	106	99	98	95	73	54	41	36
Total Temperature	**368**	**384**	**373**	**332**	**269**	**202**	**153**	**112**	**85**	**75**
1. Radiation towards atmosphere	118	134	144	143	133	116	121	126	131	137
2. Evaporation process	164	170	176	160	125	78	36	13	6	0
3. Convention process	45	45	40	35	20	20	20	20	20	20
Loss of total temperature	**327**	**349**	**360**	**338**	**278**	**214**	**159**	**159**	**157**	**157**
Gain/loss	**+41**	**+35**	**+13**	**-6**	**-9**	**-12**	**-47**	**-47**	**-72**	**-82**

4. Annual range of temperature

The maximum and minimum annual temperatures of oceanic water are recorded in august and February respectively (in northern hemisphere). The oceans and seas get heated and cooled slower than the land surfaces. On an average, the maximum temperatures of ocean surface water are recorded at 2 PM and minimum at 5 AM. The average diurnal or daily range of temperature is barely 1 degree in oceans and seas. The daily range of temperature is usually 0.3° C in the low latitudes and 0.2° C to 0.3° C in higher latitudes. The diurnal range depends on the conditions of sky, stability or instability of air and stratification of sea water.

Usually, the average annual range of temperature of oceanic water is 12° C, but there is a lot of regional variation which is due to regional variation is insolation, nature of seas, prevailing winds, location of seas etc. annual range of temperature is higher in the enclosed seas than in the open sea (e.g. Baltic sea records annual range of temperature of 4.4° C). The size of oceans and the seas also effects annual range of temperature e.g. bigger the size, lower the annual range and vice versa. The Atlantic Ocean records relatively higher annual range of temperature than the Pacific Ocean. 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.

5. Distribution Pattern of Temperature of Oceans water:

Oceans absorb more than 80 percent of the solar radiation that reaches the earth. Moreover, water has a remarkable capacity for absorbing heat.

The distribution pattern of temperature of ocean water is can be studied in two ways:

A. Horizontal distribution (Temperature of surface water)

B. Vertical Distribution (from surface water to the bottom)

Since, the ocean has 3D shape, the depth of oceans, besides latitudes, is also taken into account in the study of temperature distribution.

5.1 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 **(if Salinity is increased ➔ Boiling point will increase ➔ Evaporation will decrease).**
- **The presence of submarine ridges and sills:** Temperature is affected due to lesser mixing of waters on the opposite sides of the ridges or sills (e.g. subsurface layers in Mediterranean Sea).
- **The shape of the ocean (enclosed seas):** enclosed seas in the low latitudes record relatively higher temperature than the open seas (due to less mixing and higher overall insolation); whereas the enclosed seas in the high latitudes have lower temperature than the open seas.
- E.g. Mediterranean Sea records higher temperature than the longitudinally extensive Gulf of California.
- **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 during normal years).
- 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).
- **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).

A. Horizontal temperature Distribution of Oceans

The average temperature of surface water of the oceans is about 26.7°C (80°F) 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 uppermost 10 percent of the oceans contain more heat than the entire atmosphere. The temperature of the oceans is not uniform. It differs from latitude to latitude and from the surface to the bottom.

Factors affecting the horizontal temperature distribution of oceans are:

a) **Latitudes:** because of the spherical shape of the earth, the sun's rays are always vertical at the equator, and with the increasing distance from the equator the rays become more and more slanting. The vertical rays are capable of giving more hear than oblique rays. So, the equatorial sea waters are warmer than the polar sea waters. The average temperature of equatorial sea water is 27° C whereas at poles is -1.9° C.

b) **Ocean Currents:** the regions, where warm ocean currents flow registers higher temperatures and the areas of cold currents register lower temperatures in the oceans. The warm gulf stream between Davis strait and newfoundland drops down because of cold Labrador current washing the coasts.

c) **Prevailing winds:** the prevailing winds deflect the warm and cold currents and cause change in temperature of ocean water. For instance, the currents on the east coast in trade wind belt shift away from it and colder water rises at the coast. Hence the temperature records low in spite of the passage of warm currents. This is the reason that the temperature records lesser on the eastern coasts than on the western coasts.

d) **Ice bergs:** the temperature falls as we move away from equator. Ice bergs are found near the polar waters and can be present to be floating up to 50° latitudes. Thousands of ice bergs can be found moving away from north Atlantic Ocean. From the south the Falkland cold current and Benguela cold current carry them to far of the places. Ice bergs causes to decrease of temperature of ocean water to a great extent. They are formed after glaciers breaking into few numbers of pieces. the process of breaking of glaciers into icebergs is called claving.

e) **Unequal distribution of Land and Water:** The Northern Hemisphere has more land area than that of the Southern Hemisphere. Consequently, the oceans of the Northern are warmer than that of the Southern Oceans.

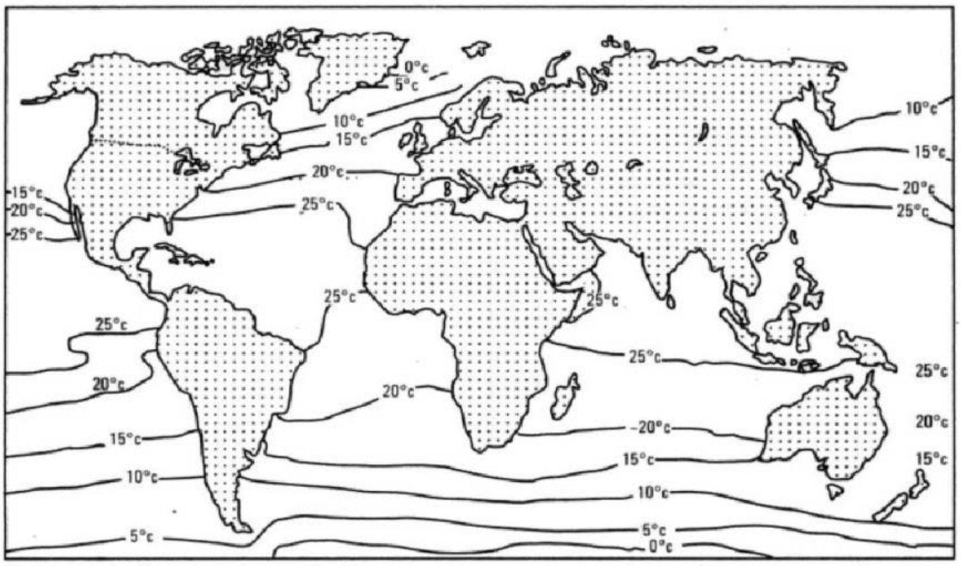
f) **The density of water:** The density of ocean water is mostly a function of its temperature and salinity. The density of waters also varies from latitude to latitude. In the areas of high salinity, the ocean waters are of a relatively higher temperature and vice versa.

g) **Evaporation Rate:** The volume of water that evaporates from the ocean surface is around 350,000 cubic kilometres per annum. However, the rate of evaporation is not uniform across different latitudes. Warmer tropical ocean waters have higher evaporation rate than the cooler temperate ocean waters.

h) **Local weather:** local weather conditions comprise different types of storms, clouding, and precipitation. In the equatorial regions, despite the vertical rays of the sun, thick cloudiness obstructs the solar radiation reaching the surface of the earth than the tropical regions. Thus, surface water temperature of oceans in the tropical region is little higher than the equatorial region. Besides, the diurnal afternoon rainfall in equatorial belts does not allow the temperature to increase further. Similarly, in the stormy weather regions the temperature of ocean water is relative lesser.

Besides, there are some other minor factors which control the horizontal temperature distribution of oceans such as location of the seas, shape of the seas, and submarine ridges, guyots etc.

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.



B. Vertical Temperature Distribution of Oceans

In general, energy and sunlight both are decreasing with increase in depth of the ocean waters. Only about 45 percent of light energy striking the ocean surface reaches a depth of about one meter, and only 16 percent reaches a depth of 10 meters. The highest temperature of the oceans is always at their surface because it directly receives the insolation. There is a gradual decrease of temperature with increasing descent. Normally, 90 percent of the solar heat is absorbed in the top most 16 m of water.

The sun's rays very effectively penetrate upto 20 m depth and they seldom go beyond 200 m depth. Consequently, the temperature decreases from the ocean surface with increasing depth, but the rate of decrease of temperature with increasing depth is not uniform everywhere. The ocean temperature falls very faster upto the depth of 200 m and thereafter the rate of decrease of temperature is slowed down. As the temperature decreases in water with increasing descent.

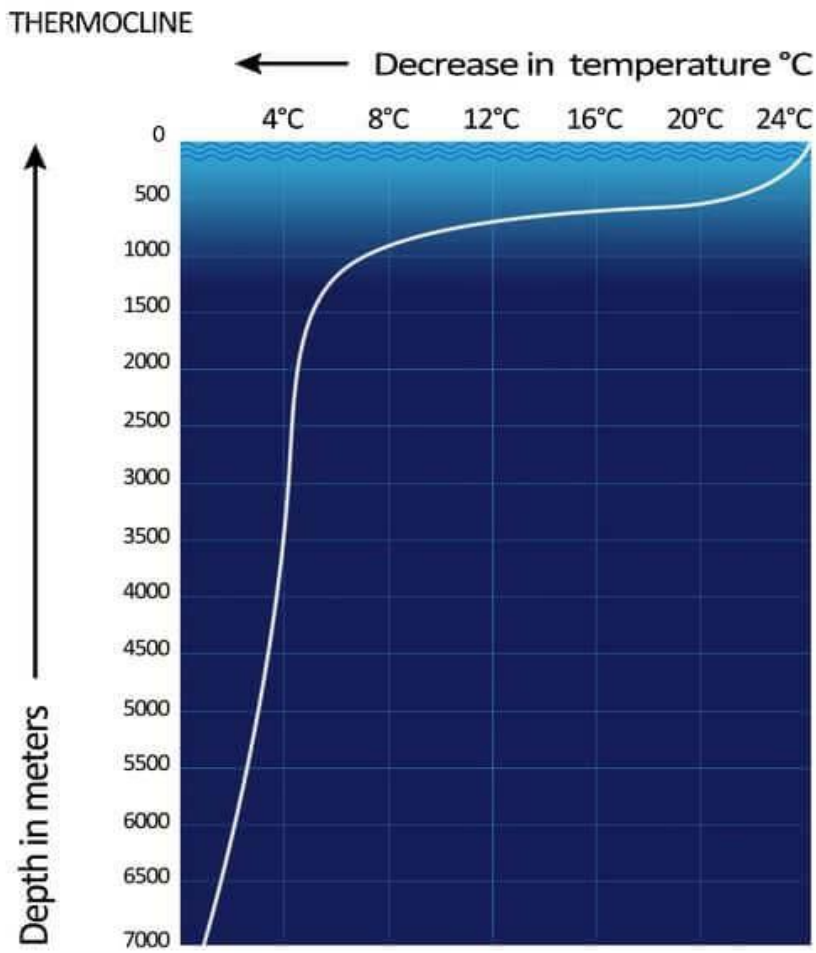
The sun's rays do not affect below 100 m of depth. Probably, 80 percent of ocean water has a temperature permanently below 40° F. the following table discloses the mean temperature for all the oceans at various depths which was collected y Murray during the challenger expedition.

Table 2: Mean Ocean Temperature at Various Depths

Depth (Fathoms)	Temperature (°C)
100	**15.8**
200	**9.95**
500	**4.45**
1000	**2.47**
1500	**1.81**
2200	**1.76**

Scientist have divided the oceans into a couple of zones based on vertical temperature distribution of oceans. They are:

- **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 (Praveenron, Wikipedia)*

The fig (11.2) discloses 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. 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.

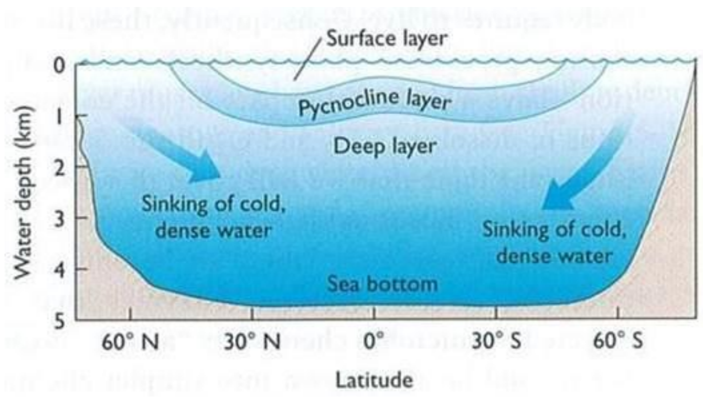
Three-Layer System

The temperature structure of oceans over middle and low latitudes can be described as a three-layer system from surface to the bottom.

1. The first layer **mixed zone** 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.
2. 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 density of water increases with increasing depth.
3. The third layer is **deep zone** it is very cold and extends up to the deep ocean floor. Here the temperature becomes almost stagnant. The ocean bottom always has a temperature which is one or two degrees Celsius above the freezing point.

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 in 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.

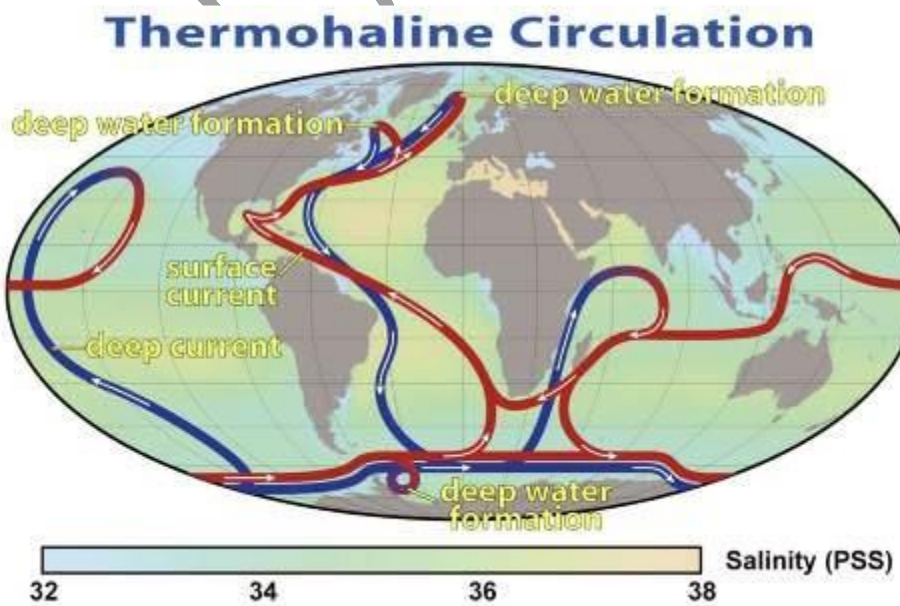


Pycnocline

Similar Terms: **Thermocline, Halocline.**

Thermohaline Circulation

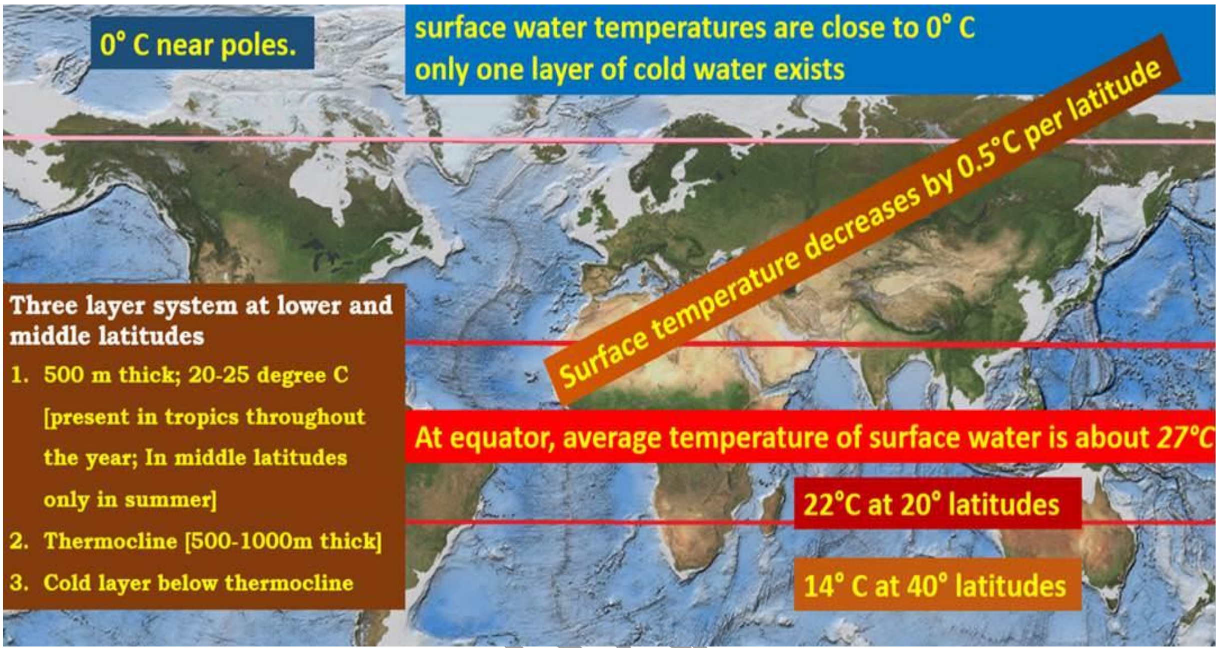
- Winds drive ocean currents in the upper 100 meters of the ocean's surface.
- However, ocean currents also flow thousands of meters below the surface.
- These deep-ocean currents are driven by differences in the water's density, which is controlled by temperature (thermo) and salinity (haline).
- This 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.



Thermohaline Circulation (Wikipedia)

General behaviour

- 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.



Ocean Temperature Distribution

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 (e.g. 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 has 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.
- 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.

Q1. How does deep water marine organisms survive in spite of absence of sunlight?

- *Photic zone (the zone that receives sunlight) is only about few hundred meters.*
- *It depends on a 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 at the depths.*
- *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.

Q2. Why is diurnal range of ocean temperatures too small?

- *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 is required to heat a Kg of water compared to heating the same unit of a solid at same temperatures and with equal energy supply).*

Module 12: Ocean Salinity

1. Introduction

There are many chemicals in ocean water that make it salty. The salts in the oceans are the result of millions of years of minerals leached and dissolved from the solid earth. Most of them get there from rivers carrying chemicals dissolved out of rock and soil. The weather also plays a role on a smaller scale, as the rain deposits mineral particles into the oceans. The main one is sodium chloride, often just called salt. The salt content in seawater is indicated by salinity(S). Salinity is defined as the ratio between the weight of the dissolved materials and the weight of the sample sea water. It means the amount of dissolved salts per unit mass of ocean water. Salinity is calculated as the number grams of dissolved salts in 1,000 grams (one kg) of seawater. It is usually expressed as parts per thousand or ppt. the average salinity of the ocean water is 35 per thousand. It means that in one kilogram of ocean water, there are 35 grams (7 teaspoons) of dissolved salts. Salinity of **24.7 ppt** (the symbol for ppt is ‰) has been considered as the upper limit to demarcate '**brackish water'.**

2. Role of ocean salinity

Salinity determines compressibility, thermal expansion, temperature, density, absorption of insolation, evaporation and humidity. The salinity of sea water not only affects the marine organisms and plant community, but it also physical properties of the oceans such as temperature density, pressure, movement of ocean water (waves and currents) etc. Salinity of ocean also influences the evaporation process because it Is lower over more saline water than over less saline water. because of about 86 percent of global evaporation and 78 percent of global precipitation takes place over the ocean, salinity of ocean surface is the key variable for understanding how input and out of fresh water influence dynamics of oceans. Through tracing salinity of ocean's surface, we can directly monitor variations in the hydrological cycle such land runoff, ice freezing and melting in seas and evaporation and precipitation processes over the oceans.

3. Composition of Ocean Water

Ocean water is weak, but comprises a complex solution of various mineral substances in diluted form, since it is active solvent. The volume of salt in ocean water is gradually increasing because it is brought in the form of particulates from the land every year. In every cubic kilometre of sea water, there exist 41 million tonnes of dissolved salts. The principle components of the ocean water are listed in the following table:

Table 12.1: Composition of Ocean Water

S. No.	Salinity constituents	Volume (1000 grams)	Percentage
1	Sodium Chloride (Nacl)	27.213	77.8
2	Magnesium Chloride ($Mgcl_2$)	3.807	10.9
3	Magnesium Sulphate ($MgSo_4$)	1.658	4.7
4	Calcium Sulphate ($CaSo_4$)	1.260	3.6
5	Potassium Sulphate (K_2So_4)	0.863	2.5
6	Calcium Carbonate ($CaCo_3$)	0.123	0.3
7	Magnesium Bromide ($MgBr_2$)	0.076	0.2
8	**Total**	**35.00**	**100.00**

The above table represents the weights of salt in grams per 1000 grams (%o) and percentages of seven important salts with a total salinity of 35 %o Dittmar. Dittmar during his challenger expedition in 1884 reported the existence of 47 types of salts in sea water out of which 7 are most important mentioned above.

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%**
- **Calcium Carbonate -0.3 %**
- **Magnesium Bromide – 0.2 %**

i. Dissolved Salts in Sea Water (gm of Salt per kg of Water)

1. Chlorine	**18.97**
2. Sodium	**10.47**
3. Sulphate	**2.65**
4. Magnesium	**1.28**
5. Calcium	**0.41**
6. Potassium	**0.38**
7. Bicarbonate	**0.14**
8. Bromine	**0.06**

9. Borate	**0.02**
10. Strontium	**0.01**

These salts are mainly of terrestrial origin. If all the salts are removed from the oceans and seas, there will be decline in sea level by 30.48 metres (100 feet). Besides salts, silver, gold and radium also occur but in minute proportion in seawater. These elements are 0.3, 0.006 and 0.0000002 mg per metric ton or part per thousand million. There are numerous nutrients in the seawater which are used by living marine organisms. These elements are silicon, nitrogen, and phosphorous. Besides, arsenic, iron, manganese and copper are also found in the seawater though in smaller quantities. Salinity is measured by electric salinity meter to an accuracy of ±0.003 %o.

4. Sources of Oceanic Salinity

the primary source of ocean salinity is land. The rain that falls on the earth surface contains some dissolved carbon dioxide from the surrounding air. As a result of this the rainwater to be slightly acidic because of carbonic acid. Rivers carry the salts in solution form from the continental areas. Most of the ocean's salts are derived from gradual processes, such as weathering and erosion of the earth's crust and mountains by the dissolving action of rains and streams. There is a lot of variation in the composition of oceanic salt and riverine salt as calcium sulphate constitutes 60 percent of river salinity of the oceans. River water comprises only 2 percent of sodium chloride. This is why, some scientists do not accept the rivers as major source of salinity of the oceans and the seas, but it may be pointed out that major portion of calcium brought by the rivers into the oceans is consumed by marine organisms. The secondary source is that the salts brought by the rivers is bit modified in the oceans. Volcanic ashes also provide some salts to the oceans. Salts become concentrated in the sea because the Sun's heat evaporates almost pure water from the surface of the ocean, leaving the salts behind. This process is part of the continual exchange of water between the Earth and the atmosphere, called the hydrologic cycle, which, along with the sources of salt, is illustrated in the following diagram.

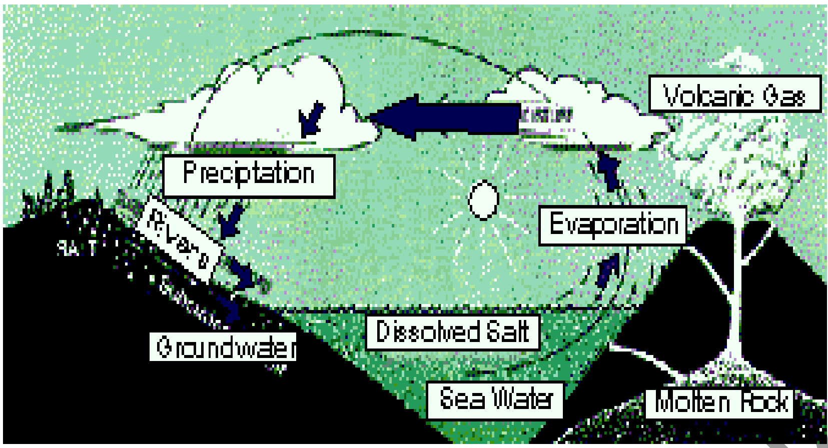


Figure 12.1: hydrological Cycle

Water vapor rises from the ocean surface through evaporation and is carried landward by the winds in the form of clouds and humidity. When the vapor in the clouds collides with a colder mass of air, the moisture condenses (changes from a gas to a liquid) and falls to Earth as rain. The rain runs off into streams, or underground as groundwater, both of which transport water back to the sea. Evaporation from both the land and the ocean again causes water to return to the atmosphere as vapor and the cycle starts anew. Natural products like dissolved salts are not the only chemicals that are transported by rivers to the sea.

5. Factors Controlling the Salinity of Oceans

The geographical distribution of salinity varies within the oceans and seas. The factors influencing the volume of salt in different oceans and seas are called as controlling factors of oceanic salinity. The significant controlling factors of ocean salinity are evaporation, precipitation, circulation of oceanic water, influx of river water, atmospheric pressure and prevailing winds etc.

5.1. **Evaporation:** At any given location on the ocean surface, the salinity depends on how much evaporation is taking place and how much freshwater is being added within. The salinity of oceans surfaces mainly depends mainly on evaporation and precipitation. There is a direct relationship between the rate of evaporation and salinity e.g., greater the evaporation, higher the salinity and vice versa. Evaporation due to high temperature with low humidity causes more concentration of salt and overall salinity becomes higher. For instance, higher salinity records near the tropics than at the equator because both the area record high rate of evaporation, but with dry air over the tropics of Cancer and Capricorn.

5.2. **Precipitation:** there is an indirect relationship between the rate of precipitation and salinity e.g., higher the precipitation, lower the salinity and vice versa. the supply of fresh water through precipitation in humid regions the high rainfall is heavier, fresh water dilute the sea water and reduce the salinity than the regions of low rainfall (evaporation is higher than the precipitation in arid and semi-arid regions).

5.3. **Circulation of Oceanic Water:** the oceans have three distinct types of movements i.e., waves, tides and currents. Ocean currents affect the spatial distribution of salinity by a continues mixing of sea surface waters. Equatorial warm currents drive away warm and salts from the wester coastal areas of the continents and accumulate them along the eastern coastal areas and the polar areas. For example, the North Atlantic drift, the extension of the Gulf stream increases salinity along the north-western coasts of Europe. Similarly, the cold currents carry the cold and less saline water from higher to lower latitudes. For example, Labrador cold current reduces the salinity along the North-Eastern coasts of North America.

5.4. **Influx of River Water:** due to the addition of freshwater from big and voluminous rivers into oceans and thus salinity is reduced at their mouths. For example, low salinity is found near the mouths of the Ganga, the Congo, the Amazon etc. The influence of influx of river water is more pronounced in the enclosed seas, for example, the Danube, the Dnieper etc, reduce the salinity in the black sea. On the other hand, where evaporation exceeds the fresh water influx by rivers, there is increase in salinity. For example, Mediterranean Sea (40%o).

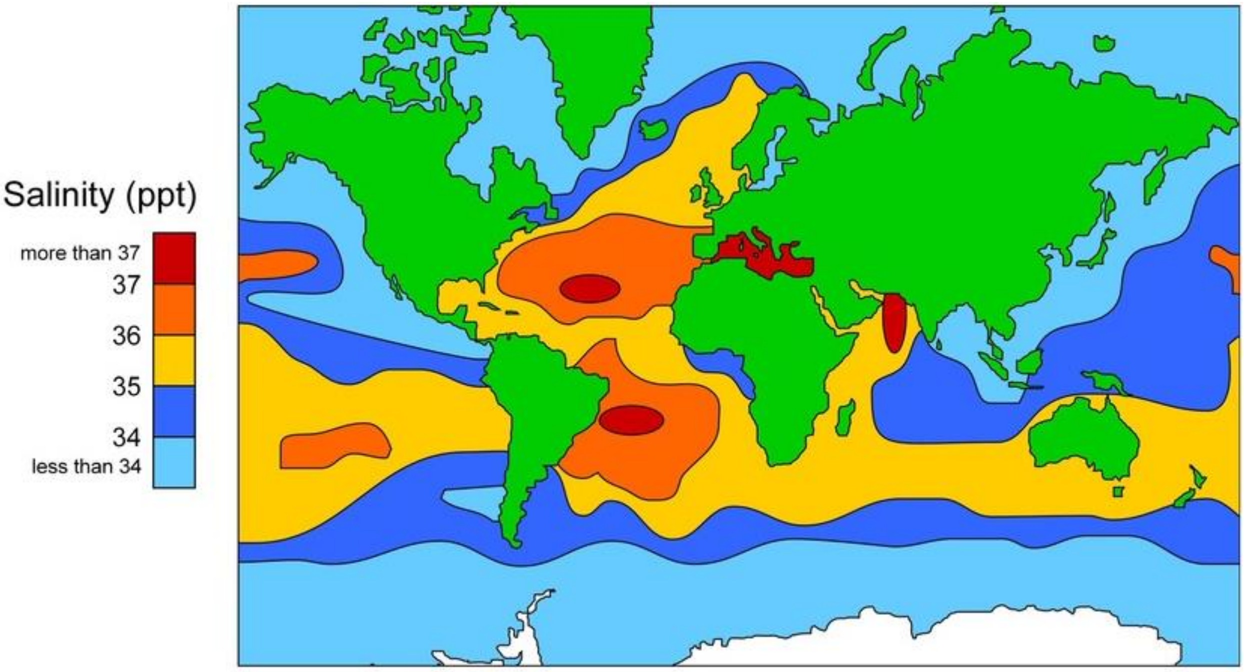


Figure 12.2

5.5. **Atmospheric Pressure and Wind Direction**: they play an important role in the distribution of surface salinity of oceans. Anticyclonic conditions with stable air and high temperature increase salinity of the surface water of the oceans. Sub-tropical high-pressure belts represent such condition to cause high salinity. Prevailing winds help in the redistribution of salt in the oceans and the seas as winds drive away saline water to fewer saline areas resulting into decrease of salinity in the former and increase in the latter. In other words, in the areas of upwelling of water less saline water moves up from below whereas the areas where water is piled up, salinity is increased. For example, the trade winds in both the hemisphere drive the ward and saline water from the eastern parts of the oceans towards the western parts causing low salinity in the former area and high salinity in the latter.

Salinity, temperature and density of water are interrelated. Hence, any change in the temperature or density influences the salinity of an area.

6. Distribution Pattern of Ocean Salinity

The normal salinity in the oceans and seas is 3.5 percent or 35 %o, but its spatial and temporal distribution varies in different oceans, seas and lakes. the disparities in ocean salinity is both horizontal and vertical. The amount of salinity varies from enclosed seas through partially closed seas to open sea. It also varies from one part of the ocean to another. The spatial distribution pattern of ocean salinity can be studied in two ways:

6.1. Horizontal distribution of ocean salinity

6.2. Vertical distribution of ocean salinity

6.1. Horizontal distribution of salinity

The horizontal distribution pattern of oceanic salinity is studies in relation to latitudes but regional distribution is also considered wherein each ocean is separately described. The salinity for normal open ocean ranges between **33 and 37**. The regions of high salinity in vast oceans coincide with high-pressure cells. Here, there is hardly any rain and subsiding dry winds cause lots of evaporation.

6.1.1. Latitudinal distribution: The areas of highest salinity are found near the tropics, from where the salinity decreases towards the equator and towards the poles. For instance, the surface salinity along the Tropic of Cancer in Atlantic Ocean is around **37** parts per thousand (ppt) while at the equator it is around **35** parts per thousand. This is because, at tropics, there is active evaporation owing to clear skies, high temperatures and the steady trade winds. On the other hand, near the equator, there is heavy rainfall, high relative humidity, cloudiness and calm air of the doldrums. Thus, the equator accounts for only 35 %o salinity and the heist salinity of 36%o is observed between 20° – 40° N latitudes. The average salinity of 35 %o is recorded between 10° – 30° S latitudes.

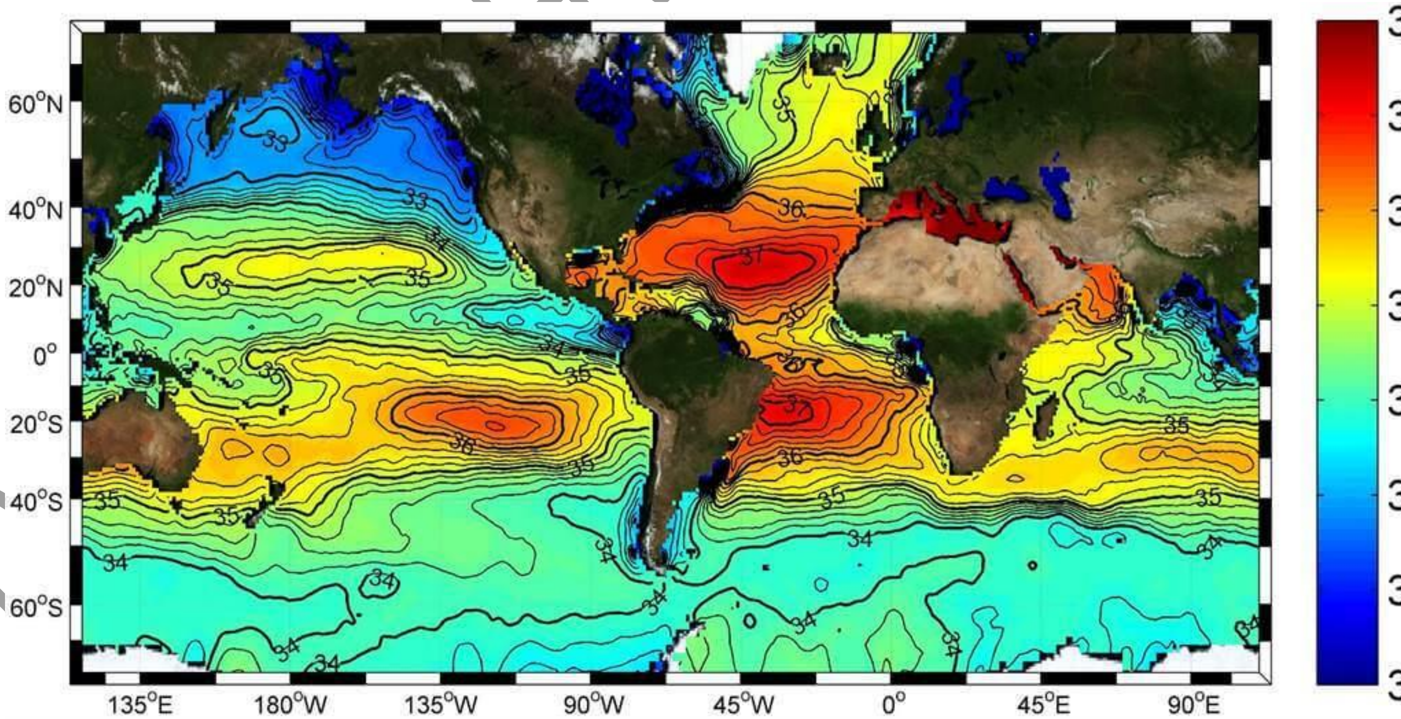


Figure 12.3

Ocean surface salinity (Source)

The zone between 40° – 60° N & S latitudes record low salinity where it ranges between 31 %o and 33%o (both north and south hemisphere). Salinity further decrease experiences in the polar zones because of very little evaporation and receive large amounts of freshwater from the melting ice. This leads to low levels of salinity, ranging between 20%o and 32%o.

Table 12.2: Latitudinal Distribution of Salinity

Latitudinal zones	Salinity (%o)
70° – 50° N	**30-31**
50° – 40° N	**33-34**
40° – 15° N	**35-36**
15° – 10° N	**34.5-35**
10° – 30° S	**35-36**
30° – 50° S	**34-35**
50° – 70° S	**33-34**

It is observed from the following table that on an average, the northern and southern hemispheres record average salinity of 34%o and 35%o respectively. The table also reveals that the maximum salinity occurs between 20° N and 40° N latitudes (36%o) and 10° S and 30° S latitudes (35%o).

6.1.2. Regional Distribution: the region wise distribution of surface salinity of the oceans and the seas is described in two ways viz;

- Distribution of salinity in individual oceans and
- Salinity zones of all the oceans together.

On the basis of their salinity levels, seas across the world can be categorized as follows:

i. **Seas with salinity levels below the normal:** They have a low salinity due to the influx of fresh water. They include the Arctic Ocean (20-35%o), North Australian Sea (33-34%o), Bering Sea (28 – 33%o), Sea of Japan (30-34%o), Baltic Sea (3-15%o), North Sea (31-35%o), Andaman Sea (30-32%o), Hudson Bay (3-15%o) etc. Their surface salinity can be as low as 21 ppt.

ii. **Seas with normal salinity levels:** These have a salinity in the range of 35 to 36 ppt. They include the Caribbean Sea, Gulf of Mexico (35-36%o), Gulf of California (25-35.5%o), Bass Strait (35%o), Yellow Sea etc.

iii. **Seas with salinity levels above the normal:** They have higher levels of salinity because of their location in regions with higher temperatures leading to greater evaporation. They include the Red Sea (39 - 41 ppt), Persian Gulf (38 ppt), Mediterranean Sea (37 - 39 ppt) etc.

6.1.2.1. Pacific Ocean:

- The salinity variations in the Pacific Ocean, is mainly due to its shape and larger areal extent.
- At the equator, its Salinity accounts 34.85ppt.
- It increases to 35 ppt between 15^0-20^0 latitudes in the northern hemisphere but it becomes still higher (36 ppt) in the southern Pacific Ocean between the same latitudes.

- Just to the south of high salinity zone (between 15^0-20^{0}S) in the southern Pacific as referred to above (36 ppt) it becomes low along the Peruvian and Chilean coasts (33 ppt).
- Low salinity is noted at river mouths (Yellow River = 30 ppt, and Yangtzekiang = 33 ppt).

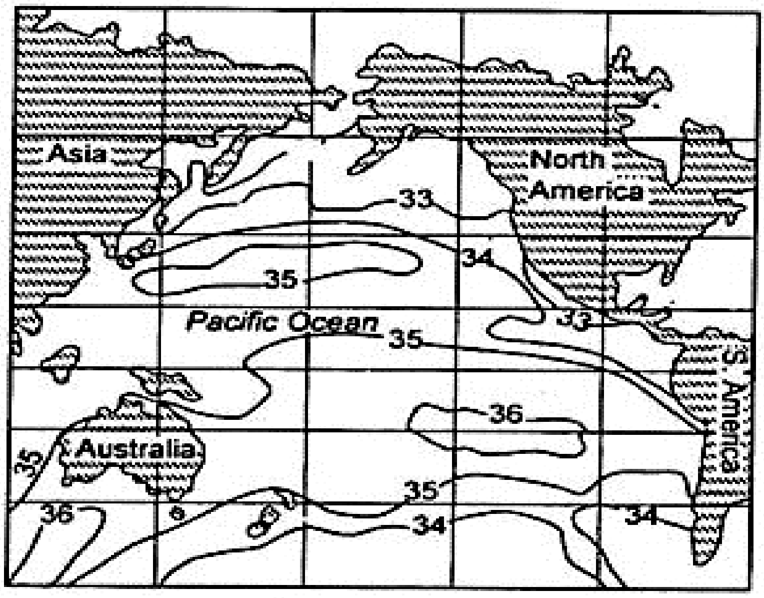


Fig. 26.1: Horizontal distribution of salinity in the Pacific Ocean.

Figure 12.4

6.1.2.2. Atlantic Ocean:

- The average salinity of the Atlantic Ocean is 35.67 ppt.
- 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 salinity increases from equator towards the tropics of cancer and Capricorn.
- **Maximum salinity (37ppt)** is observed at the central zone of North Atlantic Ocean located between 20° N and 30° N and 20° W - 60° W (high-pressure cells).
- Maximum salinity of 37 ppt in the southern Atlantic is found in a region demarcated by 12^{0}S-20^{0}S latitudes and 40^{0}W-15^{0}W longitudes.
- 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.
- The eastern marginal parts of the north Atlantic Ocean beyond 40° latitude record higher salinity than the western margin due to inflow of warm and saline water by gulf stream.

- Comparatively low salinity is observed at the river mouths, e.g., St. Lawrence 31ppt, Amazon 15ppt, Congo 34ppt, Senegal 34ppt, and Rhine 32 ppt etc.
- Baltic Sea, on the other hand, records low salinity due to influx of river water.
- It becomes as low as $2^0/_{00}$ in the Gulf of Bothnia due to influx of freshwater.

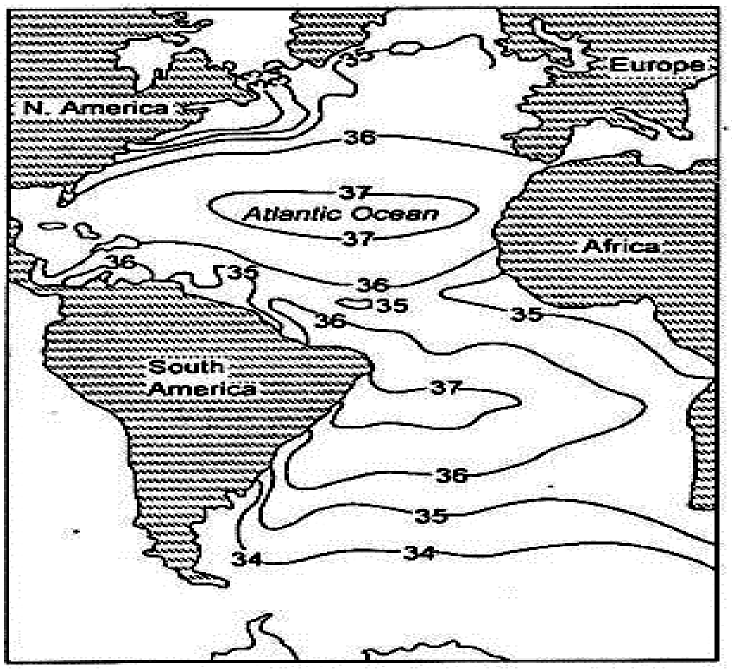


Fig. 26.2 : Horizontal distribution of salinity in the Atlantic Ocean.

Figure 12.5

6.1.2.3. Indian Ocean:

- In Indian Ocean, the geographical distribution of salinity is much variable and complex than the Pacific and Atlantic Oceans.
- The average salinity of the Indian Ocean is 35 ppt observed between 0° – 10° N latitudes.
- The low salinity trend is observed in the Bay of Bengal (33.5 ppt) due to influx of freshwater by the river Ganga.
- On the contrary, the Arabian Sea records **higher salinity (36 ppt)** due to high evaporation and low influx of fresh water.
- Higher salinity is observed along the wester coast of Australia due to dry weather.
- The partially enclosed seas show higher salinity. For example, in Persian Gulf 37 ppt at the head and 40 ppt in the interior part etc.

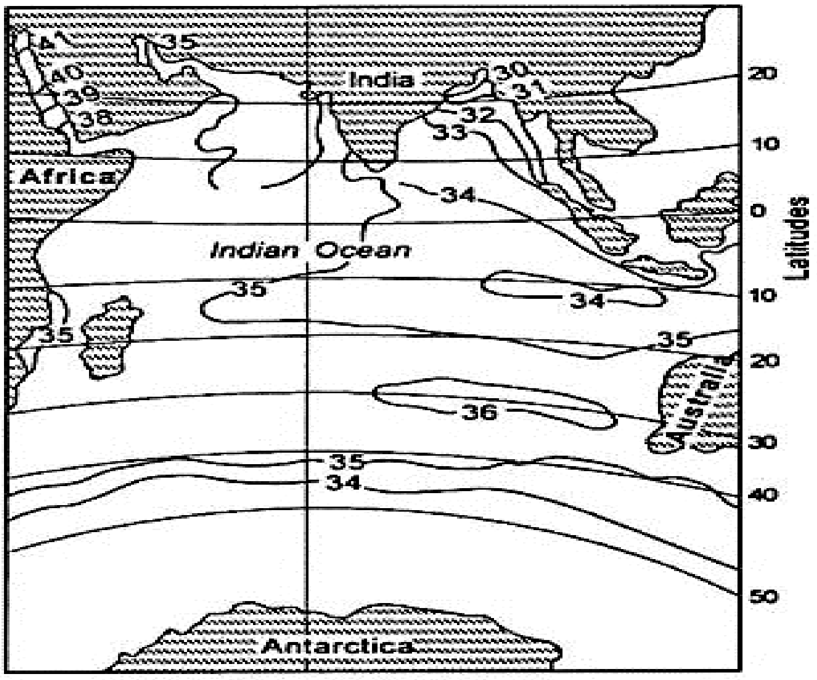


Fig. 26.3 : Horizontal distribution of salinity in the Indian Ocean.

Figure 12.6

6.1.2.4. Inland Seas and Lakes:

- The salinity in the inland seas and lakes is determined by the evaporation rate, temperature, influx of fresh water etc.
- For instance, fewer salinity of the northern part of Caspian sea (14 ppt) is due to influx of fresh water by Volga and Ural rivers, but in the southern part at Gulf of Karabugas salinity rises to 140 ppt because of high rate of evaporation than the precipitation.
- There are some water bodies which became progressively more saline due to high rate of evaporation.
- For instance, the salinity of the **Great Salt Lake – 220 ppt** (Utah, USA), the **Dead Sea 238 ppt** and the **Lake Van – 330 ppt** in Turkey is more than 200.

Highest salinity in water bodies

- **The Don Juan Pond – 440 ppt (Salt Lake, Antarctica) the hypersaline lake in the world.**
- **Lake assal – 348 ppt (Djibouti)**
- **Lake Van in Turkey (330 ppt)**

- **Dead Sea (238 ppt) the hypersaline sea in the world.**
- **Great Salt Lake, Utah (220 ppt)**

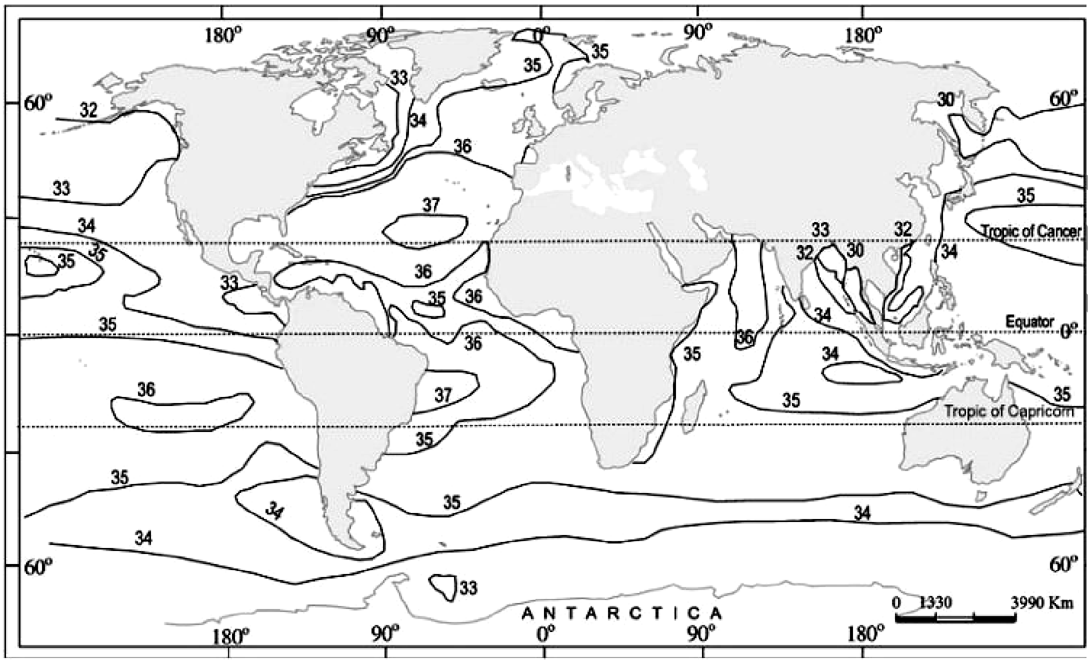


Figure13.5 : Surface salinity of the World's Oceans

Figure 12.7

6.2. Vertical Distribution of Salinity

- The salinity distribution varies with depth, but this variation again is subject to latitudinal difference.
- In general, the salinity at surface level is more in the oceans and gradually it decreases with the depth.
- The decrease is also influenced by cold and warm currents.
- Ocean salinity at depth is remains fixed, due to there is no way to loss that water or addition of the salts.
- Marked variation appears in the salinity between the surface and deep zones of oceans water.

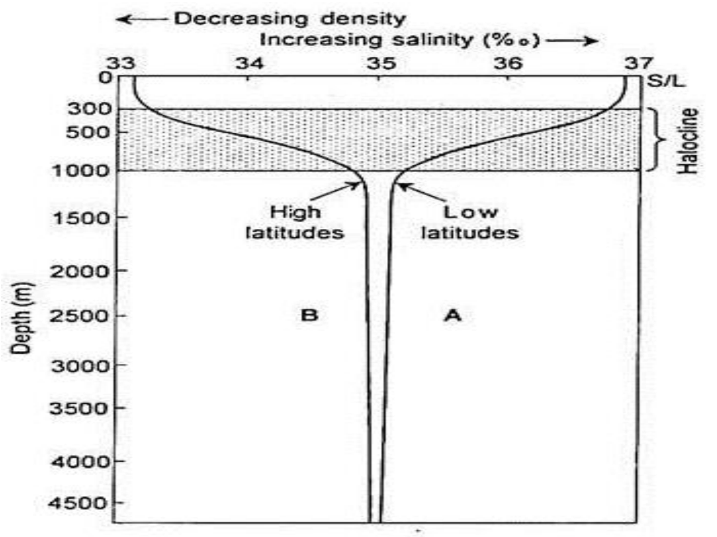


Fig. 25.10 : Relationships between ocean depth, seawater salinity and seawater density, and halocline. Modified from Thurman and Trujillo, 1999.

Figure 12.8

- Salinity, generally, increases with depth and there is a distinct zone called the **halocline** (compare this with thermocline), where salinity increases sharply.
- At the equatorial region, the oceans surface salinity is low because of influx of fresh water by daily afternoon rainfall, and towards the bottom greater salinity is found due to the presence of cold water.
- In high latitudes, salinity increases with depth due to occurrence of cold and dense water whereas in the middle latitudes, it increases up to 200 fathoms depth and then it decreases.
- High salinity seawater, in general, sinks below the lower salinity water. This leads to **stratification by salinity**.

7. Significance of Oceans Salinity:

The salinity of the oceans has certain noteworthy effects on physical property of seawater and other aspects of the oceans as follows:

i. The freezing and boiling points are greatly affected and controlled by addition or subtraction of salts in seawater.

ii. Salinity and density of seawater are positively correlated i.e. the salinity of seawater increases its density because solutes (here salts) in water have greater atomic weight than the molecules of fresh water. This is why man is seldom drowned in the seawater with very high salinity.

iii. Evaporation rate is controlled by the oceans salinity. In fact, salts in water lowers the rate of evaporation in the oceans. Thus, more saline water is less evaporated than less saline water.

iv. Spatial disparities in ocean salinity becomes potent factor in the development of ocean currents.

v. The ocean salinity affects the marine organisms and plant community badly. For example, due to the presence of higher salinity in Dead Sea no marine organisms are noticed.

vi. The ocean salinity encourages the growth of salt manufacturing.

ii. Questions

1. Salinity is expressed as the amount of salt in grams dissolved in seawater per (a) 10 gm (b) 1,000 gm (c) 100 gm (d) 10,000 gm
2. Which one of the following is the smallest ocean? (a) Indian Ocean (b) Arctic Ocean (c) Atlantic Ocean (d) Pacific Ocean

Answers: 1. B) 1000 gm 2. B) Arctic

MODULE 13: THE MOVEMENTS OF OCEANIC WATR

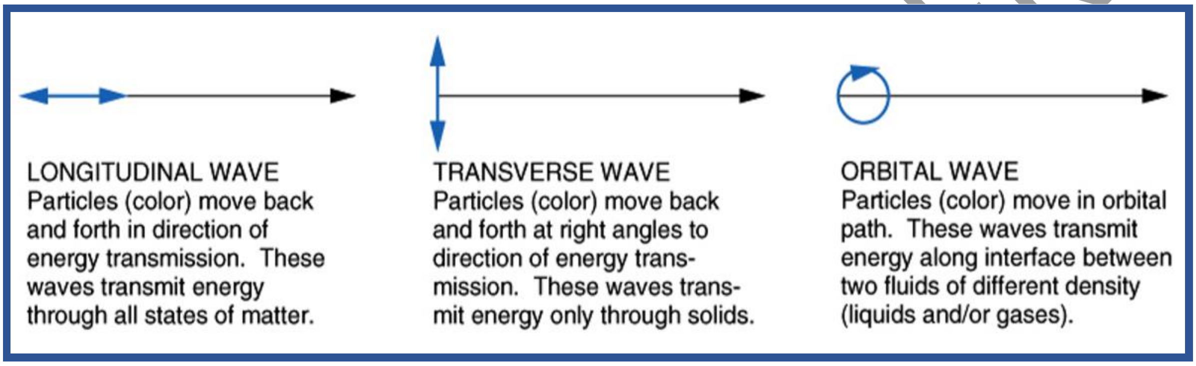
The ocean water is not static, but it is dynamic. The movements of ocean water take place under the influence of various physical properties of oceans (internal forces) such as temperature, salinity, density and the external forces like of the sun, moon and the winds. There are three major types of movements take place in the ocean waters as the following:

1. Waves
2. Tides
3. Ocean Currents

- The movements of ocean water include horizontal and vertical motions.
- The horizontal motion refers to the ocean currents and waves.
- The vertical motion refers to tides.
- Ocean currents are the continuous flow of huge amount of water in a definite direction while the waves are the horizontal motion of water.
- ocean 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.
- The vertical motion refers to the rise and fall of water in the oceans and seas.
- Due to attraction of the sun and the moon, the ocean water is raised up and falls down twice a day.
- The upwelling of cold water from subsurface and the sinking of surface water are also forming of vertical motion of ocean water

13.1. Waves

- Ideally, waves represent propagation of energy, not the water as such, which moves across the surface of the ocean.
- There are three kinds of waves namely
    - Longitudinal waves: particles move back and forth in direction of energy transmission. These waves transmit energy through all states of matter. e.g. sound waves
    - Transverse waves: particles move back and forth at right angles to direction of energy transmission. These waves transmit energy only through solids. e.g. seismic waves
    - Surface or orbital waves: particles move in orbital path. These waves transmit energy along interfaces of two fluids of different densities. These are the common wind generated waves. e.g. water waves.

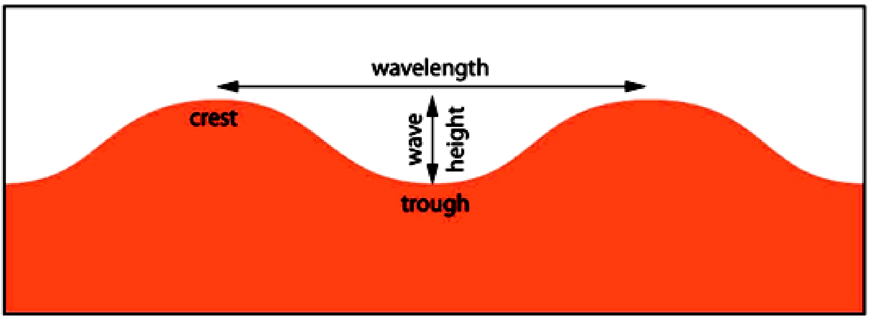


Now we will discuss about sea waves:

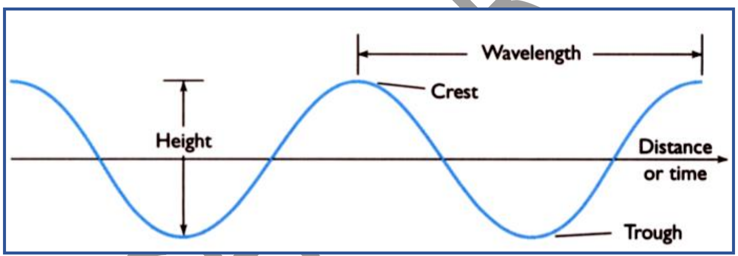
- Sea waves are all surface waves or orbital waves, and are characterised by a circular motion.
- They are nothing but the **oscillatory movements** that result in the rise and fall of water surface.
- Sea waves are a kind of horizontal movements of the ocean water and wind provides energy for the them.
- Once generated, waves can propagate as swell without wind.
- Water particles only travel in a small circle as a wave passes.
- Waves are of different sizes travel at different speeds. The large waves travel faster than the small waves.
- Since waves are not ideal, energy is dissipated and waves die out. Small waves die out or damp out, faster. But large waves can easily travel across an ocean without damping out.

Characteristics of Sea Waves:

- **Wave Crest and Trough**: A wave has two major parts: the highest point is called as the **crest** while the lowest point is called as the **trough**.
- **Wave Height**: The vertical distance from the top of a crest to the bottom of a trough of a wave.
- **Wavelength:** It is the horizontal distance between two successive crests or troughs of a wave.
- **Wave Steepness:** it is the ratio of wave Height and Length (H/L).



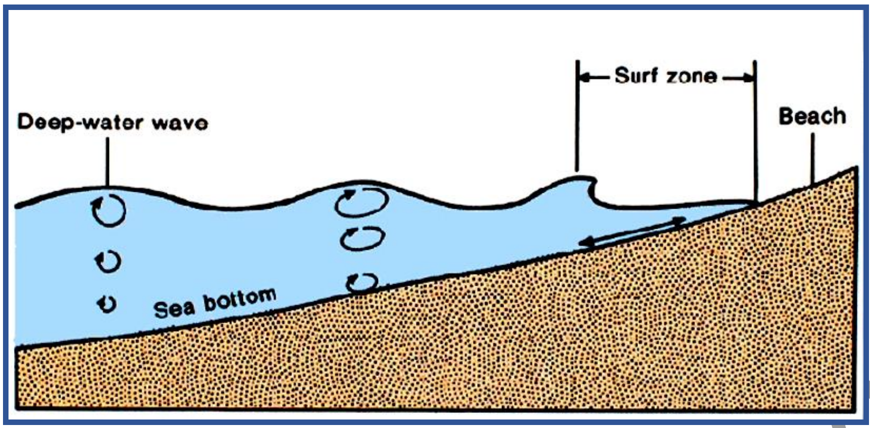
- **Wave Amplitude:** It is one-half of the wave height (wave Height/2).
- **Wave Period:** It is merely the time it takes for a wave crest or trough to pass a wavelength.
- **Wave Speed:** the distance a wave crest travels per unit time (units of distance/time). It is the rate at which the wave moves through the water, and is measured in knots
- **Wave frequency:** It is the number of crests passing a fixed location during a one second time interval (units of 1/time). Wave frequency = 1/ period.



The size and force of ocean waves depends on the following three factors:

1. Wind speed or velocity
2. The length of time of the wind blows in one direction, and
3. The distance that the wind has travelled across the open ocean. This is known as "Fetch".

The height of a sea wave is directly controlled by the amount of energy gained by it. The usual height of waves in a sea hardly exceeds 2 metres, but there are exceptions. The wave height ranges between 9 m and 15 m during cyclones and they become large in size while approaching towards the coast. A group of this kind of sea waves approaching seashore is known as "Plumage". As waves approach the shore, drag of the bottom slows the water motion near bottom, wavelength decreases while height and steepness increases. Consequently, there is net forward transport at the surface as the wave steepens. When the height of sea waves reaches 1/7 wave length, the wave becomes unstable and breaks. Open ocean breakers known as "white Caps" are produced. The waves breaking with foam are known as "Surf".

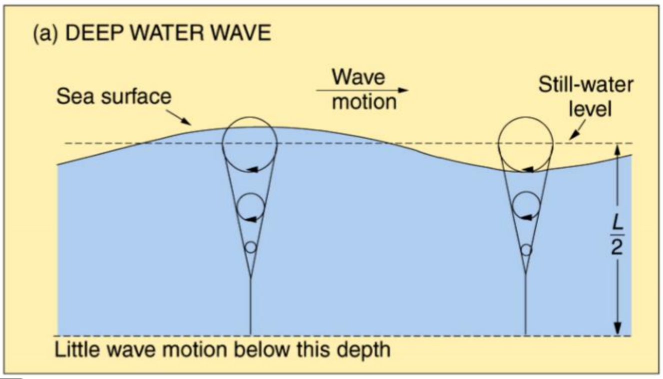


Classification of Sea Waves:

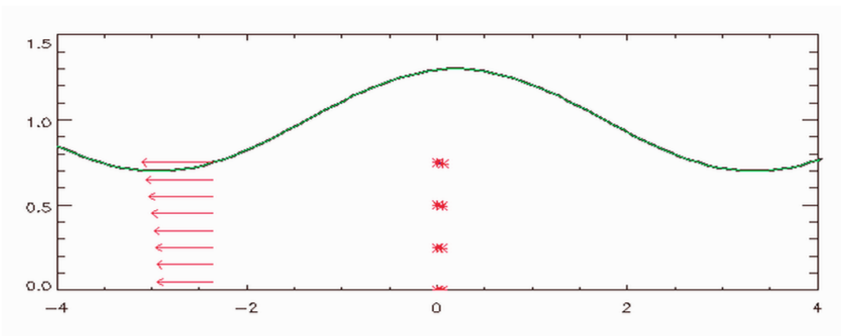
The sea waves are classified into various groups based on their characteristics and formation as the following:

Based on their characteristics

i. Deep Water Waves: Deep-Water waves travel in water that is deeper than 1/2 the wave's wavelength. Depth > L/2. Deep water waves have nearly ideal shape and thus propagate energy but very little mass. Speed is a Function of Wavelength Only. Speed = Wave Length / Wave Period. Waves with Longer Wavelength move faster than Waves with Shorter Wavelength.



ii. Shallow Water Waves: Shallow-Water waves travel in water that is shallower than 1/20 of the wave's wavelength. Depth < L/20. Shallow water waves are not ideal and propagate both energy and mass. Speed is a Function of Depth Only. Speed = 3.13 × (depth)1/2.



iii. Intermediate Waves: these are known as **transitional waves**. Intermediate waves are neither purely "deep" nor "shallow". L/20 < Bottom Depth < L/2. Wave Speed is a Complicated Function of Both Wavelength & Depth.

13.2. Tides

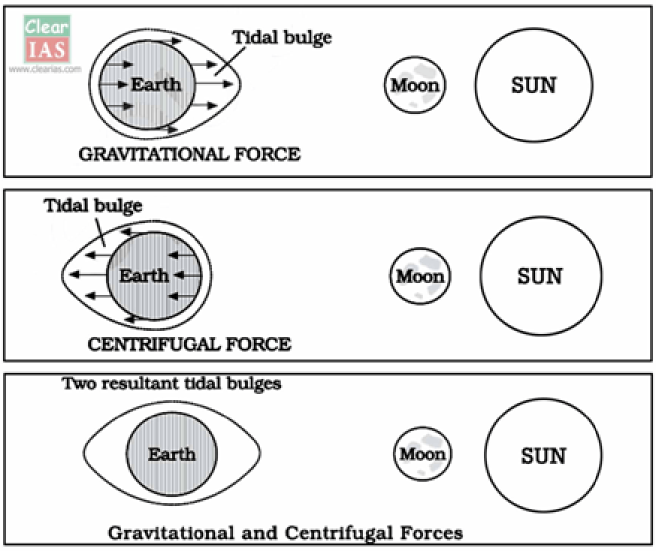
- The tides, another most important among various types of movements in the sea, are actually more complicated and present a striking paradox. Since the force of motion, which presumably is believed to act impartially on all parts of the globe, does not do, so the nature of tide and its range becomes a matter of local characteristics. The universality and everyday occurrence of tides has been a matter of interesting study, since the earliest times.
- Tides influence the ocean water to the deepest part of the basin. Tides act in response to the secretive force of the moon's attraction.
- The tide waves occur in the rhythmic rise and fall of water in response to the effects of oscillating forces by Moon, Sun and the rotation of the earth. The water in oceans rises regularly twice a day at regular intervals.
- The periodical rise and fall of the sea level, once or twice a day, mainly due to the gravitational forces of the sun and the moon, are called **tides**. The sea waves generated by tides are called **tidal waves**.
- The study of tides is very complex, spatially and temporally, as it has great variations in frequency, magnitude and height.

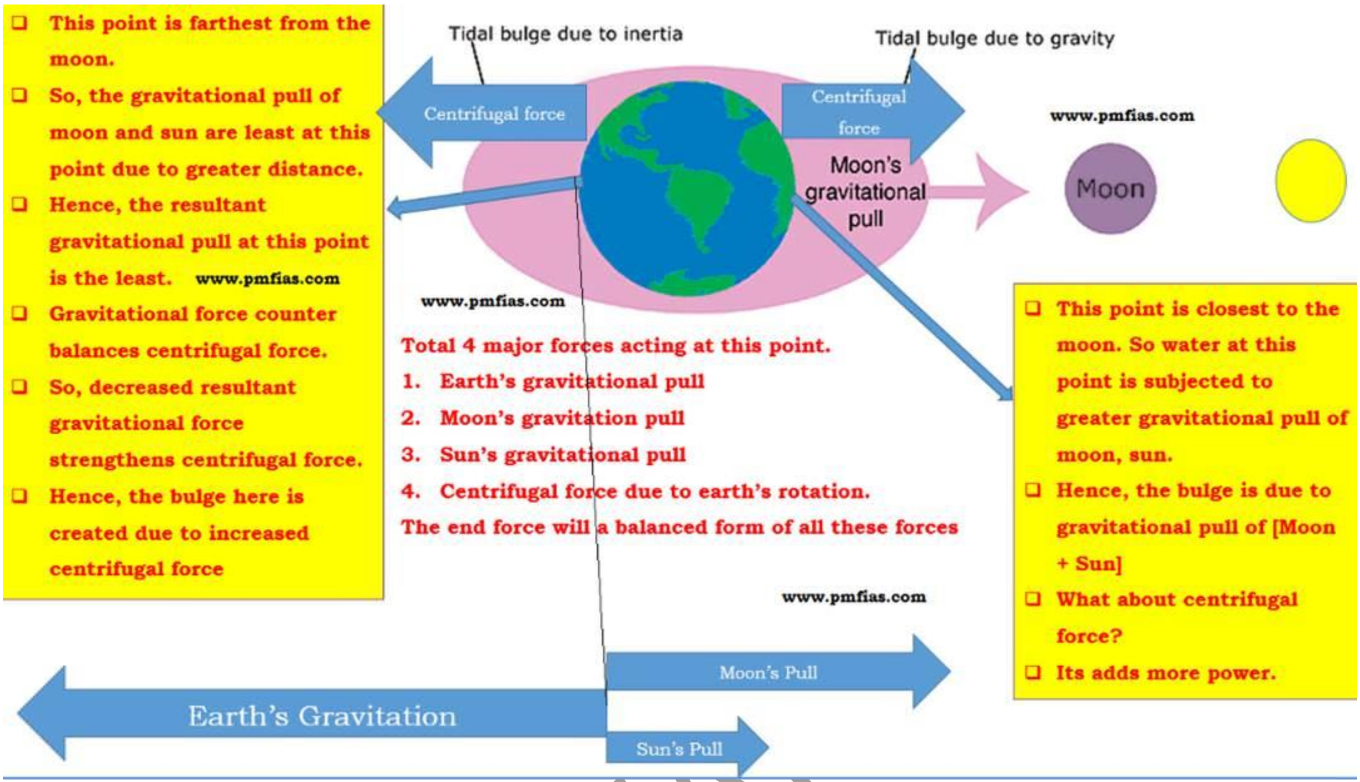
Origin of Tides:

The origin of tides in the oceans is primarily concerned with the gravitational forces of the sun and the Moon. It may be pointed out that the earth rotates from west to east and revolves around the sun. similarly, the moon rotates from west to east and revolves around the earth, along an elliptical orbit, so that the distance between the moon and the earth changes during different times in every month. It is evident that the earth's outer surface, which is opposite to that surface of the earth, which faces the moon is 390400 km away from the moon's surface. The gravitational force of the moon will be maximum at the earth’s surface facing the moon, while it will be maximum at the opposite side of the earth. Consequently, the water of the earth’s surface facing the Moon is attracted and pulled and high tide occurs.

- 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.

ii. Tidal Bulge: Why there are two tidal bulges?





Formation of Tidal Bulges

- Together, the gravitational pull and the centrifugal force are responsible for creating the two major **tidal bulges** on the earth.
- 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 to 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.

i. Why is there a tidal bulge on the other side?

- 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**.
- This creates the **second bulge** away from the moon.

ii. 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.

iii. 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.

1. Tides based on Frequency

a. Semi-diurnal tide

- It is the most common tidal pattern, featuring **two high tides and two low tides each day (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.

High tide and low tide (Wikipedia). Hide tides and low tides are formed due to earth's rotation relative to moon

i. 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.**

Flood (between low tide and high tide)

Ebb (between high tide and low tide)

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 of the changing relative positions of the moon and the sun)

- 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.
- **Southampton** experiences **tides 6-8 times a day (2 high tides from North Sea + 2 high tides from English Channel + 2 low tides from North Sea + 2 low tides from English Channel)**.
- This happens because the **North Sea** and the **English Channel** push the water at different intervals.

Southampton

b. 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.

c. Mixed tide

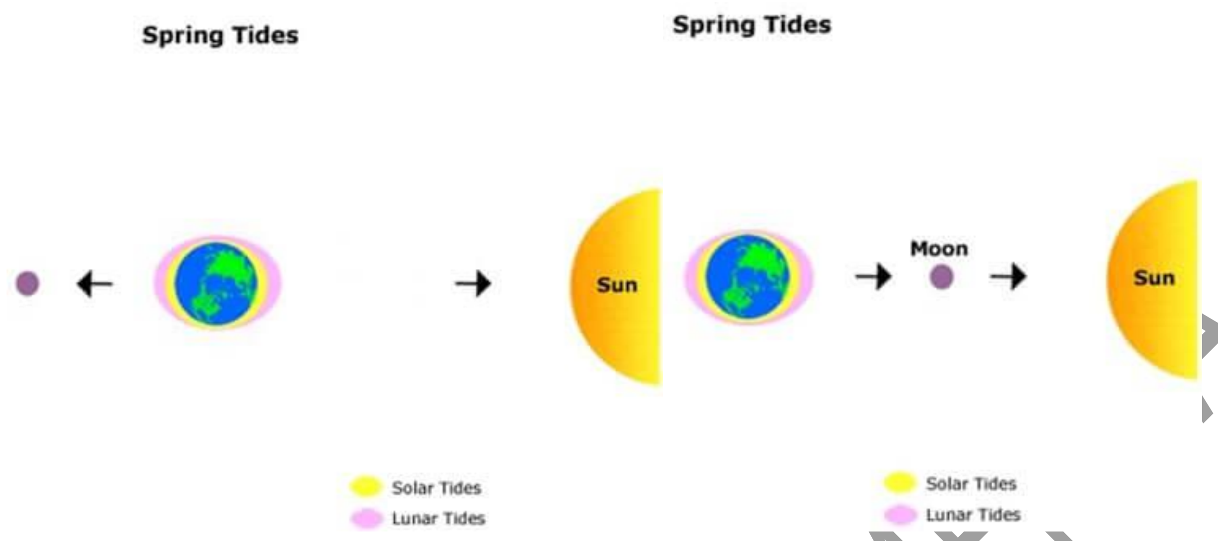
- Tides having variations in height are known as mixed tides. These tides generally occur along the **west coast of North America** and on many islands of the Pacific Ocean.

2. 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.

a. Spring tides

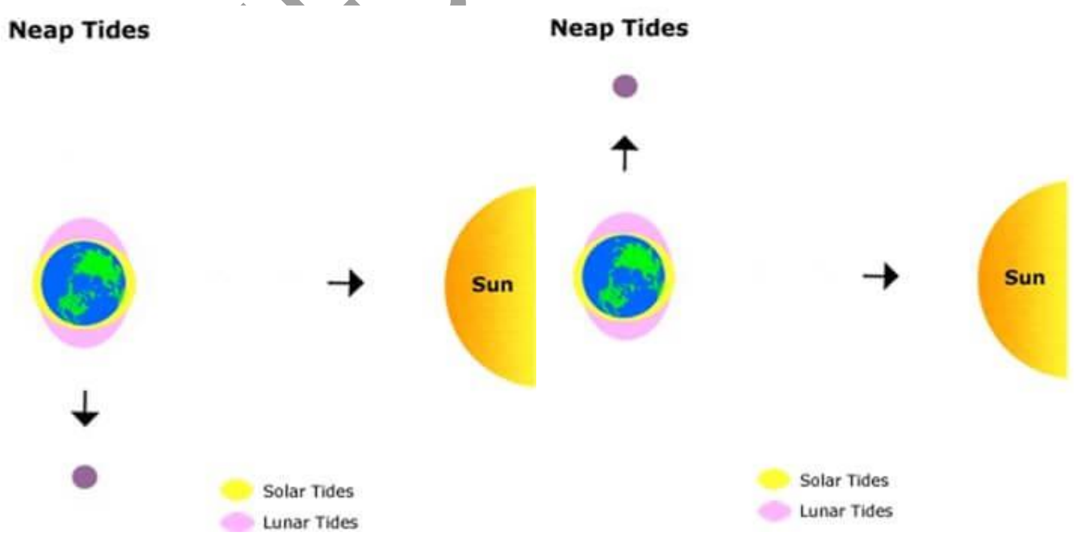
- The position of both the sun and the moon in relation to the earth has direct bearing on tide height.
- When **the sun, the moon and the earth are in a straight line**, the height of the tide will be higher.
- These are called **spring tides** and they occur **twice a month**, one on **full moon period**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



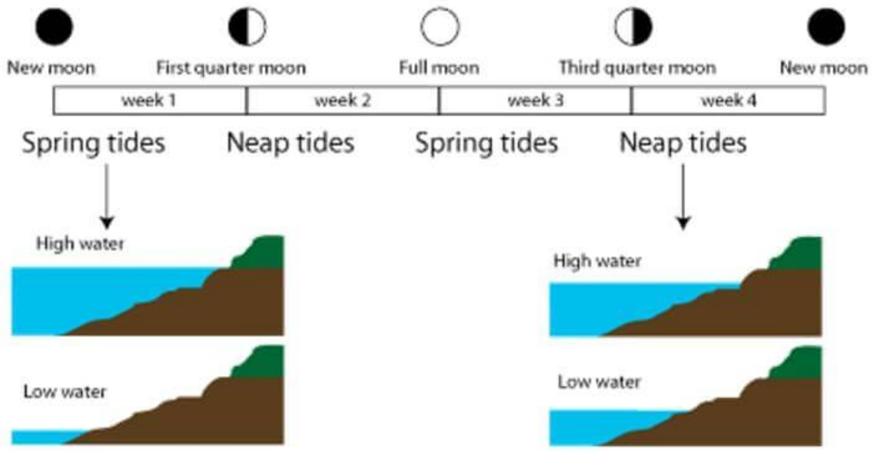
Spring Tides (New Moon and Full Moon)

b. 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.**



Neap tide (Half Moon – First Quarter and Last Quarter)

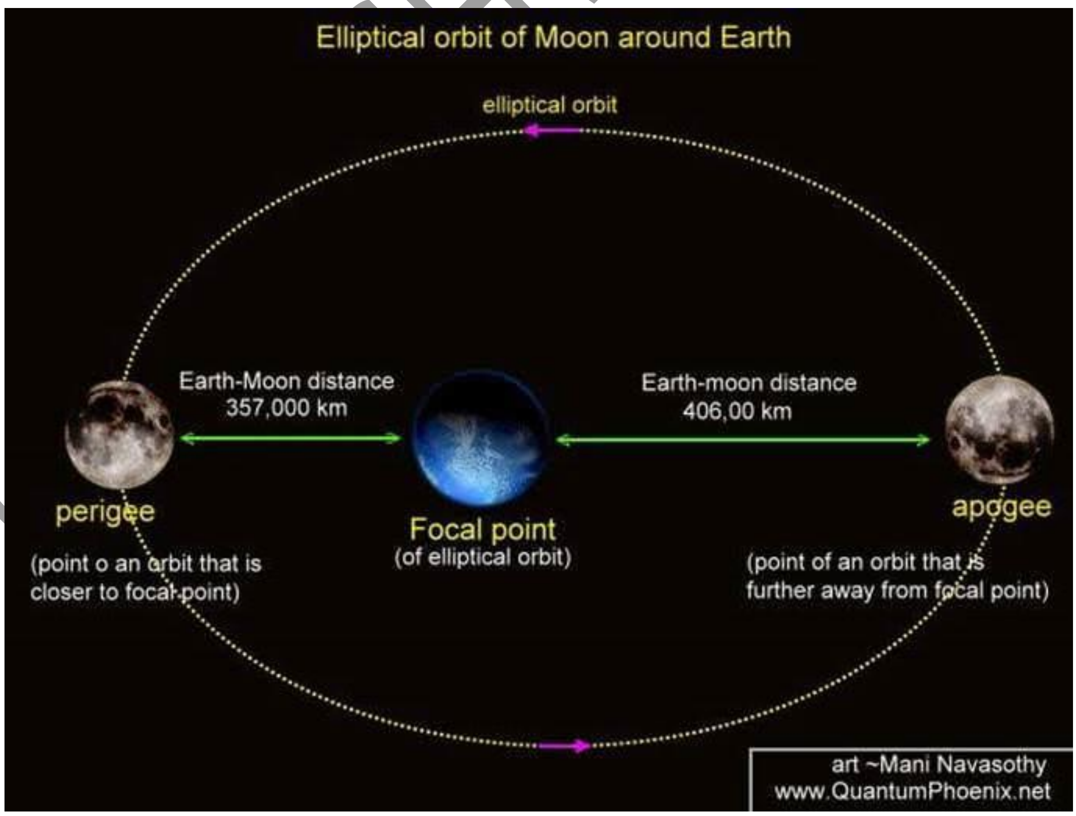


Spring tide: high tide is higher than normal; low tide is lower than normal

Neap tide: high tide is lower than normal; low tide is higher than normal

3. Magnitude of tides based on Perigee and Apogee

- 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.



Perigee and Apogee

4. Magnitude of tides based on Perihelion and Aphelion

- 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.

iv. 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.

i. Navigation

- Tidal heights are very important, especially harbours near rivers and within estuaries having shallow **'bars'** 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. **Port of London and Haldia Port, Kolkata (tidal ports)** have become important ports owing to the tidal nature of the mouths of the Thames and Hooghly respectively.

ii. 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.

iii. Desilting

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

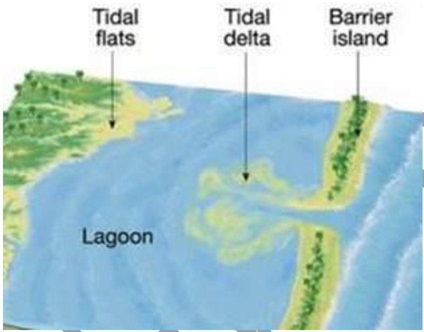
iv. Other

- Tides are used to generate electrical power (in Canada, France, Russia, and China).

- A 3 MW tidal power project was constructed at **Durgaduani in Sundarbans of West Bengal**.

v. Characteristics of Tides

- 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**.



Landform affected by tides

- When the tide is channelled between islands or into bays and estuaries, they are called **tidal currents (tidal bore is one such tidal current).**
- **Funnel-shaped bays** greatly change tidal magnitudes. Example: **Bay of Fundy — Highest tidal range.**
- The highest tides occur in the **Bay of Fundy in Nova Scotia, Canada**. The tidal bulge is **15-16 m**.

Bay of Fundy in Nova Scotia, Canada

vi. 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 channel is called a tidal current.

Tidal bore

- 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 favourable 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.

Enormous Tidal bore

- 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).

vii. 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.
- The tidal-bore affected estuaries are the rich feeding zones and breeding grounds of several forms of wildlife. Tidal bores have an adverse impact on the ecology of estuaries.
- 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.

1. Multiple Choice Questions

1. Upward and downward movement of ocean water is known as the:

(a) tide

(b) wave

(c) current

(d) none of the above

2. Neap 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 coastline.

(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

Answers: 1. A) Tide 2. D) None 3. C) Perigee 4. B) July

Module 14: Ocean Movements

1.0. INTRODUCTION

- 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.
- **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 (meaning waves with large wavelengths)**.

1.2. OCEAN CURRENTS

- Ocean currents are more or less similar to water streams or rivers flow in oceans. They represent a **regular** volume of water in a **definite** path and direction.
- The ocean current is defined as a general horizontal movement of a mass of water in a fairly definite direction over great distances in oceans.
- The ocean currents are most powerful of all the dynamics of oceanic waters because they drive ocean water for thousands of kilometres away and their movements influence on climatology of various regions.

1.3. ORIGIN OF OCEAN CURRENTS:

The ocean currents are originated because of collective outcomes of various reasons performing internally as well as externally. In reality, the factors controlling the origin and other characteristics of ocean currents, are related to different characteristics of ocean waters, rotational mechanism of the earth, external factors or atmospheric factors, topographic characteristics of the coastal regions and oceanic bottom relief features. The factors which influences ocean currents by two types of forces namely:

1. **Primary forces:** These initiate the movement of water. these include atmospheric related factors such as heating by solar energy or insolation, prevailing winds, rainfall and evaporation, and other factors related to rotation of the earth like Coriolis force and gravitational force.
2. **Secondary forces:** These forces influence the currents to flow. The local variations in the physical properties of the oceans like temperature differences, salinity differences and density variations etc within the oceans generate currents to flow.

viii. 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)**

1. Influence of insolation

- The amount of insolation received at the earth's surface and consequent temperature decreases from equator towards the poles. Because of high temperature in the equatorial regions the water density decreases.
- Due to the heating by solar energy the sea waters expand.

- Due to the expansion of volume and low density, near the equator, the ocean water is about 8 cm higher in level than in the middle latitudes.
- Normally, the flow is from east to west.

2. Influence of Prevailing winds (atmospheric circulation)

- Prevailing winds (e.g., trade winds, westerlies and polar winds) are most important among the factors influence the origin of surface ocean currents.
- Frictional force of the strong wind sets the surface water of the ocean in movement.
- These strong winds are not random breezes; the major winds that most often effect the creation of ocean currents are the Trade Winds, which blow from east to west and the Westerlies, which blow from west to east.
- Prevailing winds are held responsible for both magnitude and direction (Coriolis force) of the ocean currents.
- Example: **Monsoon winds** are responsible for the seasonal reversal of ocean currents in the Indian ocean.
- The pattern of oceanic circulation roughly resembles to the atmospheric circulation pattern of the earth.
- The air circulation over the oceans in the middle latitudes is mainly anticyclonic (sub-tropical High-Pressure Belt). The oceanic circulation pattern also resembles with the same.
- At higher latitudes, where the wind flow is mostly cyclonic, the oceanic circulation follows this pattern.

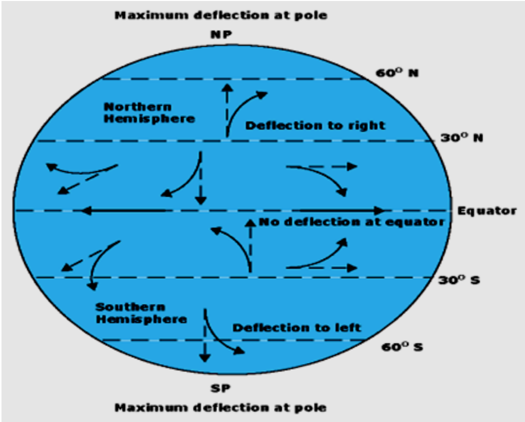
3. Influence of Rainfall and evaporation

- The water level in oceans comparatively rises in the areas with low rate of evaporation and high precipitation than those areas which record low rate of precipitation but high rate of evaporation.
- In reality, both rainfall and evaporation are also associated to salinity and density of ocean water.
- The low evaporation combined with high rainfall diminishes the amount of salinity and thus condenses water density. As a result of this, the sea level rises slightly.

- Thus, surface ocean currents are generated from the high level water areas towards the low water levels.
- The ocean currents are originated at the equator due to high water level caused by exceptionally heavy rainfall during daily afternoons and relatively low rate or evaporation move as warm surface currents towards poles.
- Similarly, the ocean currents also originated at polar areas, because of high water level as a result of low rate or evaporation and influx of large volume of water due to ice melting, moves as cold subsurface currents towards low latitudes.

4. Influence of Coriolis force or Ferrell's law

- The rotation of the earth causes two main inertial forces: the centrifugal force pointing straight up (which is mostly swamped out by gravity), and the Coriolis force which points perpendicular to an object's motion.
- In other words, the earth's rotation on its own axis from west to east results in the origin of deflective force.
- The deflective force causes by the Coriolis Effect is caused Coriolis force.
- The Coriolis force explains why winds circulate around high and low pressure systems as opposed to blowing in the direction of the pressure gradient.
- The Coriolis force has its own way in many geographical phenomena, most important being the deflection of the general direction of ocean currents.
- 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.
- The perpendicular nature of the Coriolis force causes objects in motion to travel in great circles on the surface of the earth. Systems in the northern hemisphere circle **clockwise** while systems in the southern hemisphere circle **counter-clockwise**.



- It is important to note that the magnitude of the deflection, or "Coriolis effect," varies significantly with latitude. The Coriolis Effect is zero at the equator and increases to a maximum at the poles.
- The deflection is proportional to wind speed; that is, deflection increases as wind strengthens.
- The resultant balance between the pressure force and the Coriolis force is such that, in the absence of surface friction, air moves parallel to isobars (lines of equal pressure). This is called the geotropic wind.
- A **gyre** is any large system of rotating surface ocean currents, particularly those involved with large wind movements. Gyres are caused by the Coriolis Effect; planetary vorticity along with horizontal and vertical friction, which determine the circulation patterns from the wind curl (torque).
- These **gyres** develop great circular currents in all the ocean basins. One such circular ocean current is the **Sargasso Sea**.

5. Influence of Gravity

- Gravity tends to pull the water down to pile and create gradient variation.
- Gravity causes the denser water to fall, pushing away the less dense water, which shoots sideways and rises.

ix. Secondary Forces Responsible for Ocean Currents

- The differences in Temperature and salinity in the oceans are the secondary forces. They create density variations in sea water.

- The variations in density of sea water influence **vertical movement** of ocean currents (vertical currents).

6. Influence of Temperature

- Higher temperatures, such as near the equators, cause a given mass of water to expand and therefore drop in density. But, the density of water becomes comparatively greater in the polar areas
- Consequently, water moves due to expansion of volume from equatorial region (of higher temperature) to polar areas (colder areas) of relatively very low temperature.
- There is movement of ocean water below the water surface in the form of subsurface current from colder polar areas to warmer equatorial areas in order to balance the loss of water in the equatorial areas.
- Thus, the poleward surface current and Equatorward subsurface currents form a complete circulatory system of ocean water.
- The Gulf Stream and Kuroshio warm currents moving from equator towards north are examples of such currents.

7. Influence of Salinity

- The salinity in ocean affects the density of ocean water and density variation causes ocean currents.
- The salinity intensifies the density of ocean water. If two areas in ocean with equal temperature are characterized by variation in salinity, the area of higher salinity will have greater density than the area of lesser salinity.
- In general, the denser water sinks and moves as subsurface current whereas less saline water moves towards greater saline water as surface current.
- In other words, ocean currents on the water surface are generated from the areas of less salinity to the areas of greater salinity.
- Such surface and subsurface system currents are triggered by disparities in salinity is created in open and enclosed seas. **For example**, the current flows from the Atlantic Ocean to the Mediterranean Sea via Gibraltar Strait is produced owing to the difference in salinity.

8. Influence of Density

- Fluctuations in both temperature and salinity lead different regions of ocean water to have different densities.
- Also, lower salt content causes a given mass of water to be lower in density.
- The variations in density of sea water influence **vertical movement** of ocean currents (vertical currents).
- The sea water with high salinity is denser than water with low salinity. Similarly, cold water is denser than warm water.
- Giant convection loops of ocean currents form as the lighter (hotter, less salty) regions of water rise and flow to replace the heavier (colder, more salty) regions of water.

- As we study earlier, the denser water tends to sink, while relatively lighter water tends to rise.
- The effect of density-driven currents is fundamentally a result of the interplay heating from the sun, earth's gravity, and salinity differences.

  Besides the primary and sources, there are some other factors that modify the ocean currents.

Factors modifying the ocean currents

There are certain other factors which do not help the generation of ocean currents, but they bring about important changes in the direction, velocity and extent of already generated ocean currents.

1. Nature of sea coast
2. Seasonal changes
3. Oceanic Bottom topography.

1. Nature of sea coast:

- The shape and direction of sea coasts obstructs and modify the ocean currents. When ocean currents are approaching a coast, they start flowing in accordance with the alignment of the coast.

- The South Atlantic Equatorial Current reaching the coast of Brazil in South America is obstructed and diverged into two branches by the topographic interference of the eastern extension of Brazil, Cape San Rogue.

- The Northern branch, one branch of the South Equatorial Current (known as Gulf stream) enters into the Caribbean Sea moving along the north-eastern coast of South America. The other branch moves off along the Brazilian coast towards the south. It is called the Brazil Current.

- So is the case with Gulf Stream, whose direction of flow clearly demonstrates the effect of the eastern coast of the United States of America.
- Similarly, in the Pacific Ocean also different islands exercise dominant control on the movement and direction of ocean currents by the nature of their coasts.

- Another most evident example of the modifying effect of the nature of coasts is found in the Indian Ocean where ocean currents induced by the monsoon are influenced by the shape of the coastline of the Indian Peninsula.

2. Seasonal Changes:

- In certain regions, the direction of ocean currents experiences a change in response to the changes in the seasons. Ocean currents in the north Indian Ocean change their direction with the seasonal reversal of winds, the monsoons.

- During the winter monsoon (the northeast monsoon) the surface current moves south along the coast of Indian Peninsula and turns west at about 10°N latitude.
- During the southwest monsoon the North Equatorial Current disappears, and a part of the South Equatorial Current starts flowing north along the Somali coast as the Somali Current.
- Seasonal changes cause displacement of the pressure as well as the wind belts. Therefore, the ocean currents, particularly the North Equatorial and the South Equatorial currents in the Atlantic and the Pacific oceans are also affected by the seasonal changes.

3. Oceanic Bottom topography:

- Ocean currents are also subject to modification by the bottom relief of the oceans.
- The physical irregularities present on the bottom of oceans influence and modify the flow of currents to a large extent.
- Currents of the mid-latitudes as well as the Polar Regions in particular are all the more affected by the bottom relief of the oceans.
- Whenever there are physical barriers obstructing the path of deeper currents, they tend to deflect to the right of their path in the northern hemisphere and to the left of their path in the southern hemisphere.
- Even the surface currents are also affected by the presence of such physical obstructions. For example, due to the presence of the Mid-Atlantic Ridge almost all the currents of the North Atlantic Ocean are affected to a certain extent.
- When the Gulf Stream crosses the Wyville Thompson Ridge, various changes occur in it. The maximum effect of the bottom relief on ocean currents is visible in those parts of the oceans where there are many islands or where the water is shallow because of the presence of continental shelf.
- The bottom relief of the oceans controls the details of the deep oceanic circulation.
- The Arctic Sea waters, for example, are not allowed to move southward at depth due to the obstruction caused by the submarine ridges north of Iceland and across the Bering Sea.
- Similarly, the submarine ridges present at the entrance to the Arctic Basin prevent any bottom waters formed in the Arctic Sea from coming into the open ocean of the Atlantic.
- The Bering Strait is very narrow (58 km) and very shallow (58 m). So there is a very small exchange of water through it between the Pacific and Arctic Oceans.
- Water of the Atlantic origin enters the Arctic Basin mainly through the deep channel between Greenland and Spitzbergen and spreads towards the east, along the margin of the continental shelf of Eurasia, and towards the North Pole.
- In addition to the above-mentioned factors, the earth's rotation on its axis plays very important role in modifying the direction of the path of motion of the ocean currents.

- As stated earlier, the Coriolis force produced due to the rotation of the earth tends to deflect all the currents of the northern hemisphere to the right of their path and those of the southern hemisphere to their left.

1.4. General Characteristics of Ocean Currents:

These characteristics arise as a result of interplay of the above-mentioned factors and include the following:

1. The general movement of the currents in the northern hemisphere is clockwise and in the southern hemisphere, anti-clockwise (Fig. 3.7). 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.
2. The warm currents move towards the cold seas and cool currents towards the warm seas.
3. In the lower latitudes, the warm currents flow on the eastern shores and cold on the western shores. The situation is reversed in the higher latitudes—the warm currents move along the western shores and the cold currents along the eastern shores.
4. Convergence along which the warm and cold currents meet and divergence from which they move out in different directions also control the currents.
5. The shape and position of coasts play an important role in guiding the direction of currents.
6. The currents flow not only at the surface but also below the sea surface. Such currents are caused by the differences in salinity and temperature. For instance, heavy surface water of the Mediterranean Sea sinks and flows westward past Gibraltar as a sub-surface current.

1.5. Types of Ocean Currents

Based on depth the ocean currents may be classified based on their depth as **surface currents** and **deep water currents**:

- Surface currents constitute about 10 per cent of all the water in the ocean; these waters are the upper **400 m** of the ocean.
- 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.
- For instance, heavy surface water (due to increase in salinity) of the Mediterranean Sea sinks and flows westward past Gibraltar as a sub-surface current.

Based on temperature ocean currents are classified as **cold currents** and **warm currents**.

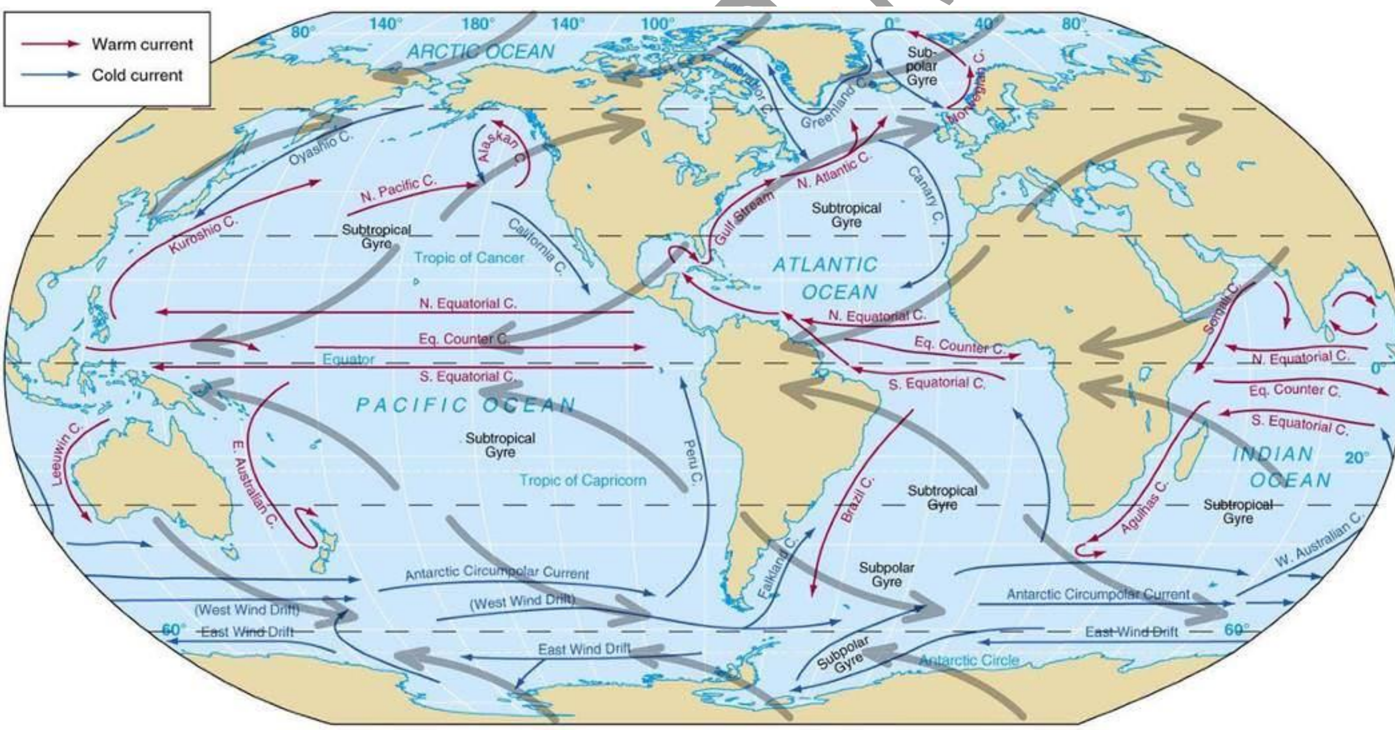
- **Cold-water ocean currents** occur when the cold water at the poles sinks and slowly moves towards the equator as **subsurface flow**.

- **Warm-water currents** travel out from the equator along the surface, flowing towards the poles to replace the sinking cold water.

1. Cold currents are usually found on the **west coast of the continents** (because of clockwise flow in northern hemisphere and anti-clockwise flow 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 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.

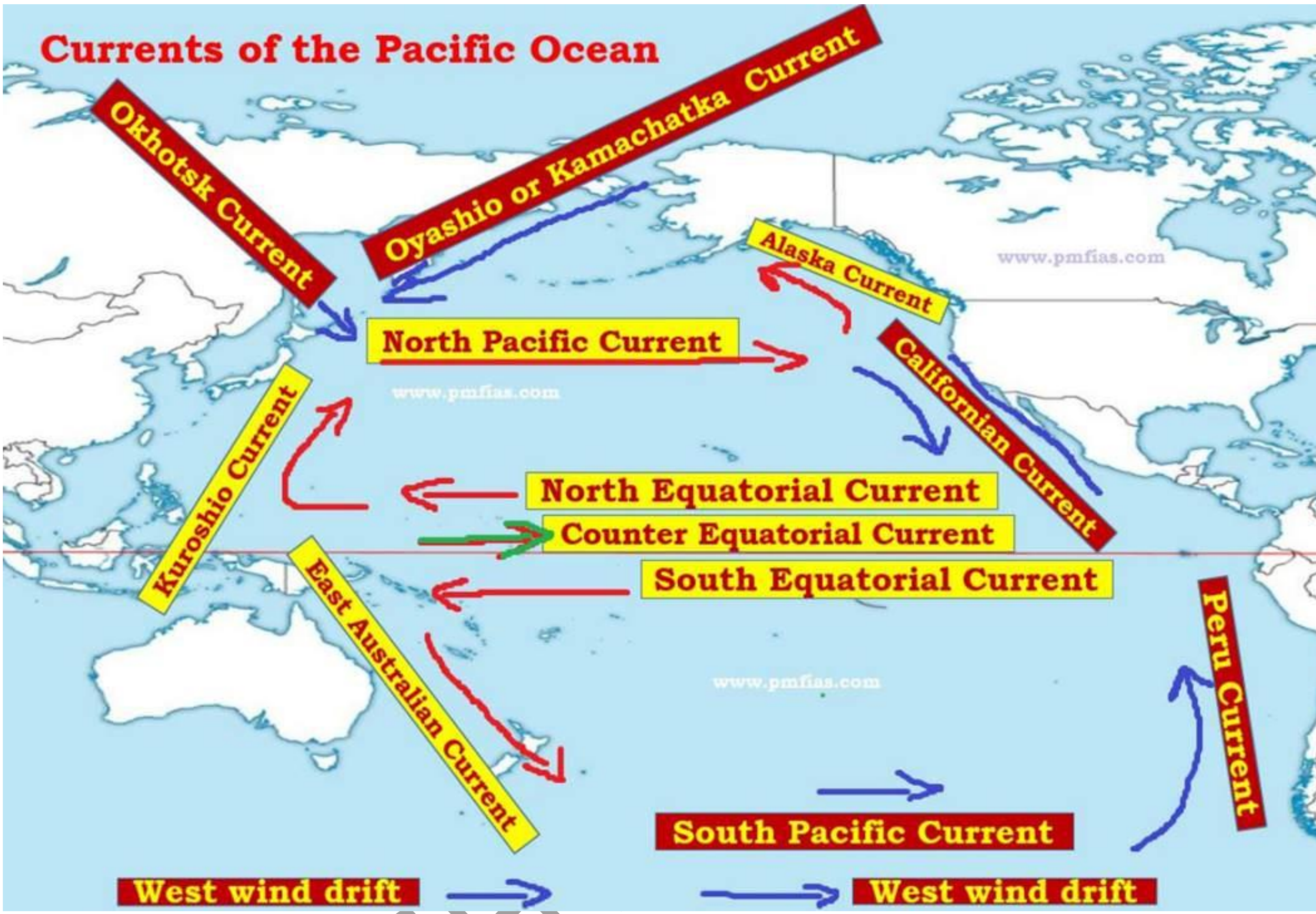
Convergence: *warm and cold currents meet.*

Divergence: *a single current splits into multiple currents flowing in different directions.*



Cold and Warm Ocean Currents

1.6. Pacific Ocean Currents



Pacific Ocean Currents

1.6.1.1. Equatorial currents – warm

- 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.**
- This raises the level of western Pacific (near Indonesia and Australia) ocean by few centimetres.
- And this creates a **counter-equatorial current** which flows between the north equatorial current and the south equatorial current in **west-east** direction.

Factors that 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 (calm region in equatorial low-pressure belt) in between the north equatorial current and the south equatorial current.

1.6.1.1.1.1. Question Prelims 2015: What explains the eastward flow of the equatorial counter-current?

a) The Earth's rotation on its axis

b) Convergence of the two equatorial currents

c) Difference in salinity of water

d) Occurrence of the belt of calm near the equator

Point 1: Earth's rotation creates Coriolis force, but Coriolis force is not responsible for counter-current.

Point 2: Convergence is a prerequisite, but not all convergences lead to counter-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.

Answer: D

1.6.1.2. Kuroshio current – warm

- The north equatorial current turns northward off the Philippines to form the **Kuroshio current.**
- It flows in the **sub-tropical high-pressure belt,** and its northern part is under the influence of **westerlies.**

1.6.1.3. Oyashio Current and Okhotsk current – cold

- **Oyashio flows** across the east coast of Kamchatka Peninsula to merge with the warmer waters of Kuroshio.
- Okhotsk current flows past **Sakhalin Islands** to merge with the Oyashio current off Hokkaido (Northern Japanese Island).
- The **convergence of cold and warm currents makes the zone one of the richest fishing grounds**.

1.6.1.4. North-Pacific current – warm

- 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.

1.6.1.5. Alaska current – warm

- The northern branch of North-Pacific current 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.

1.6.1.6. Californian current – cold

- The southern branch of the North-Pacific 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.

1.6.1.7. East Australian current – warm

- 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.

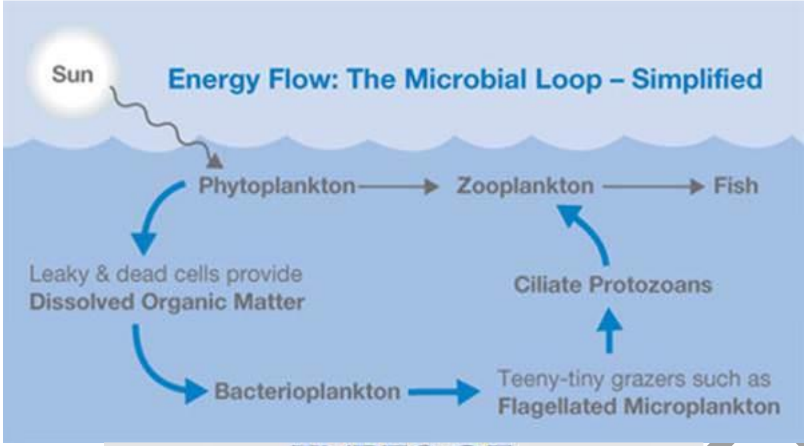
1.6.1.8. Peru current or Humboldt Current – cold

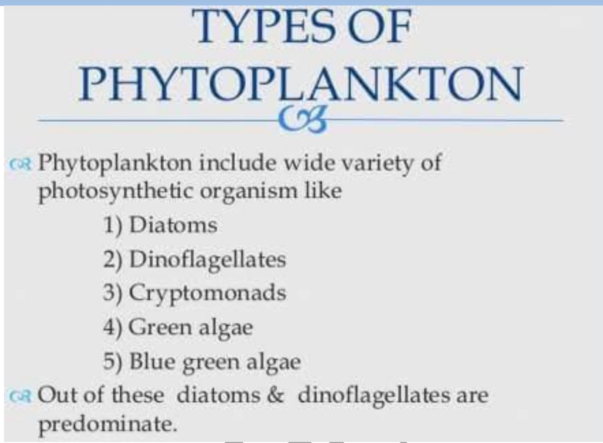
- Reaching the south-western coast of South America, South Pacific current turns northward as the Peru current. It is a cold current, which finally feeds the south equatorial current, thus completing the great circuit.
- **The zone where Peru Cold current meets the warm equatorial ocean waters is an important fishing zone**.

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.
- They are insignificant players in the marine ecosystem compared to the phytoplankton as they only inhabit a narrow zone around the coast.





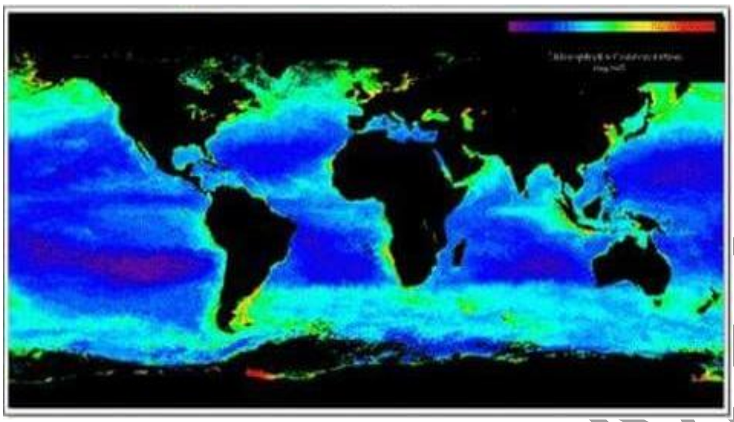
Aquatic Food Web (Left); Types of Phytoplankton (Right)

Why are cold and warm current mixing zones the good fishing grounds? Why are tropical waters highly unproductive?

- Algae and other plants are able to **photosynthesise** 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 photosynthesise.
- 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.



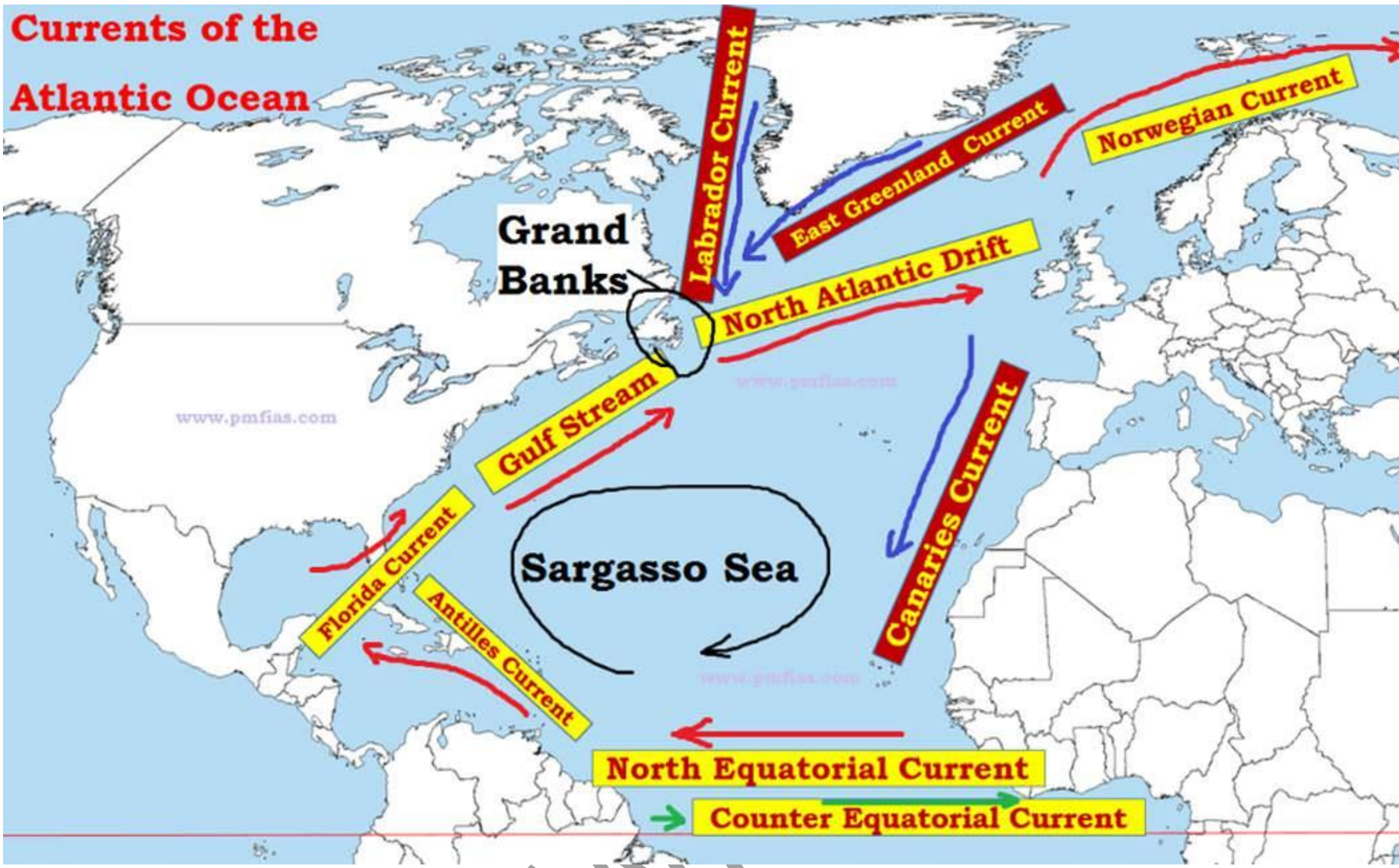
Phytoplankton production is highest at high latitudes

This is one of the reasons why cold and warm currents convergence zones (mixing happens; e.g. Grand Banks) and upwelling zones (e.g. upwelling near Peruvian coast) 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.

1.7. Atlantic Ocean Currents



North Atlantic Ocean Currents

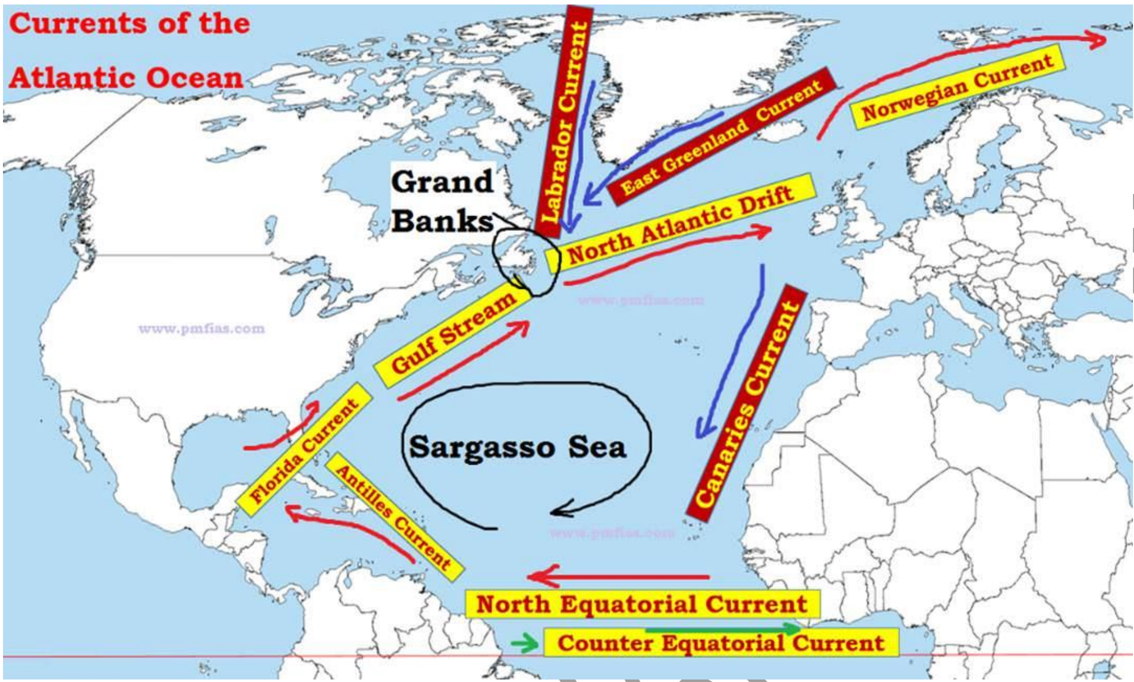
1.7.1.1. Equatorial Atlantic Ocean Currents – warm

- 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 centimetres.
- And this creates a **counter-equatorial current** which flows between the north equatorial current and the south equatorial current in **west-east** direction.

1.7.1.2. Antilles current – warm

- 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.



1.7.1.3. Gulf Stream and North Atlantic Drift – warm

- **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 up to 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.**

1.7.1.4. Norwegian current – warm

- 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.

1.7.1.5. Sargasso Sea – a sea without a land boundary

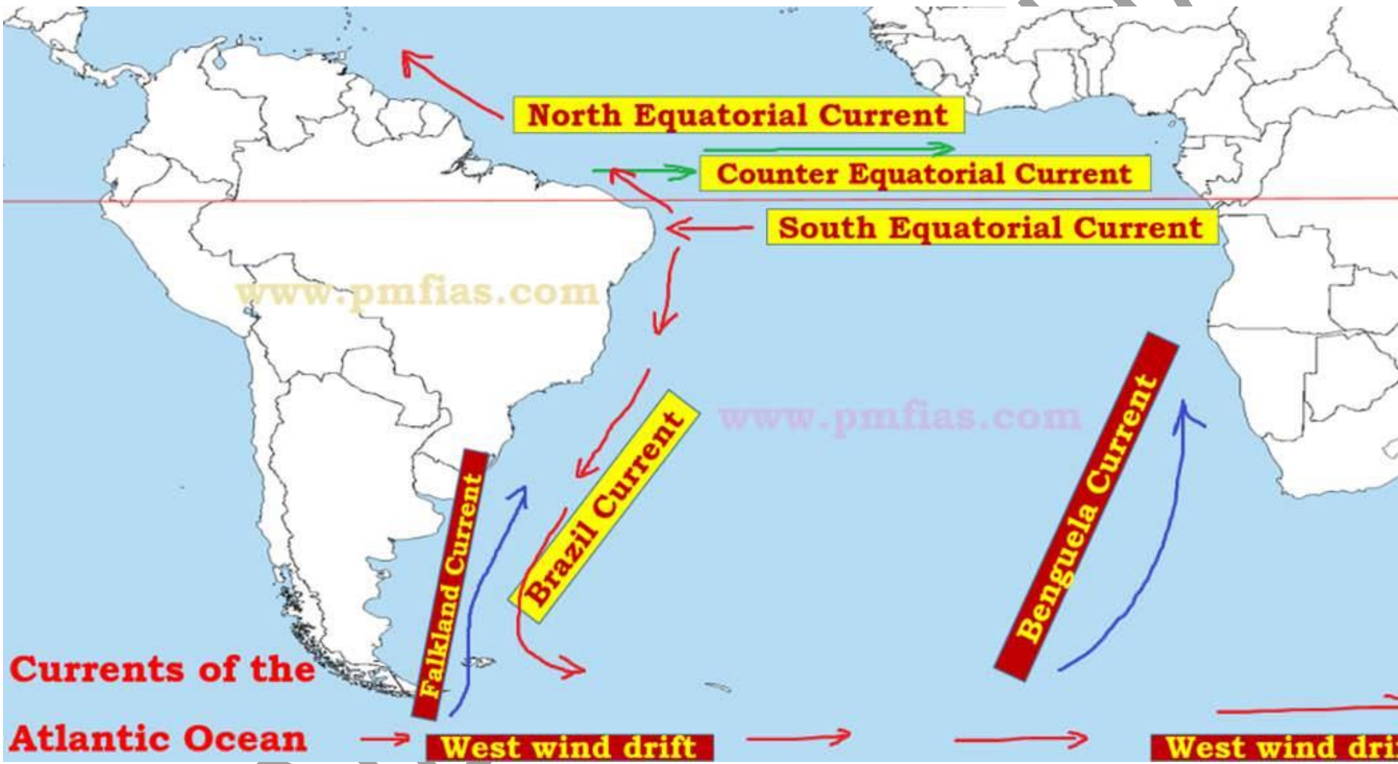
- The Sargasso Sea is a region in the gyre in the middle of the North Atlantic Ocean.
- It is the only sea on Earth which has **no coastline.**
- It is bounded on the
    1. west by the **Gulf Stream**;
    2. north, by the **North Atlantic Current**;
    3. east, by the **Canary Current**; and
    4. south, by the **North Atlantic Equatorial Current**.
  - This system of ocean currents forms the **North Atlantic Gyre**.
  - All the currents deposit the marine plants they carry into this sea.

Sargasso Sea

1.7.1.6. 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.**



South Atlantic Ocean Currents

1.7.1.7. Brazil current – warm

- 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 Antilles 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.

1.7.1.8. Benguela current – cold 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.

Prelims 1999: In the given map, which one of the following pairs of ocean currents are shown?

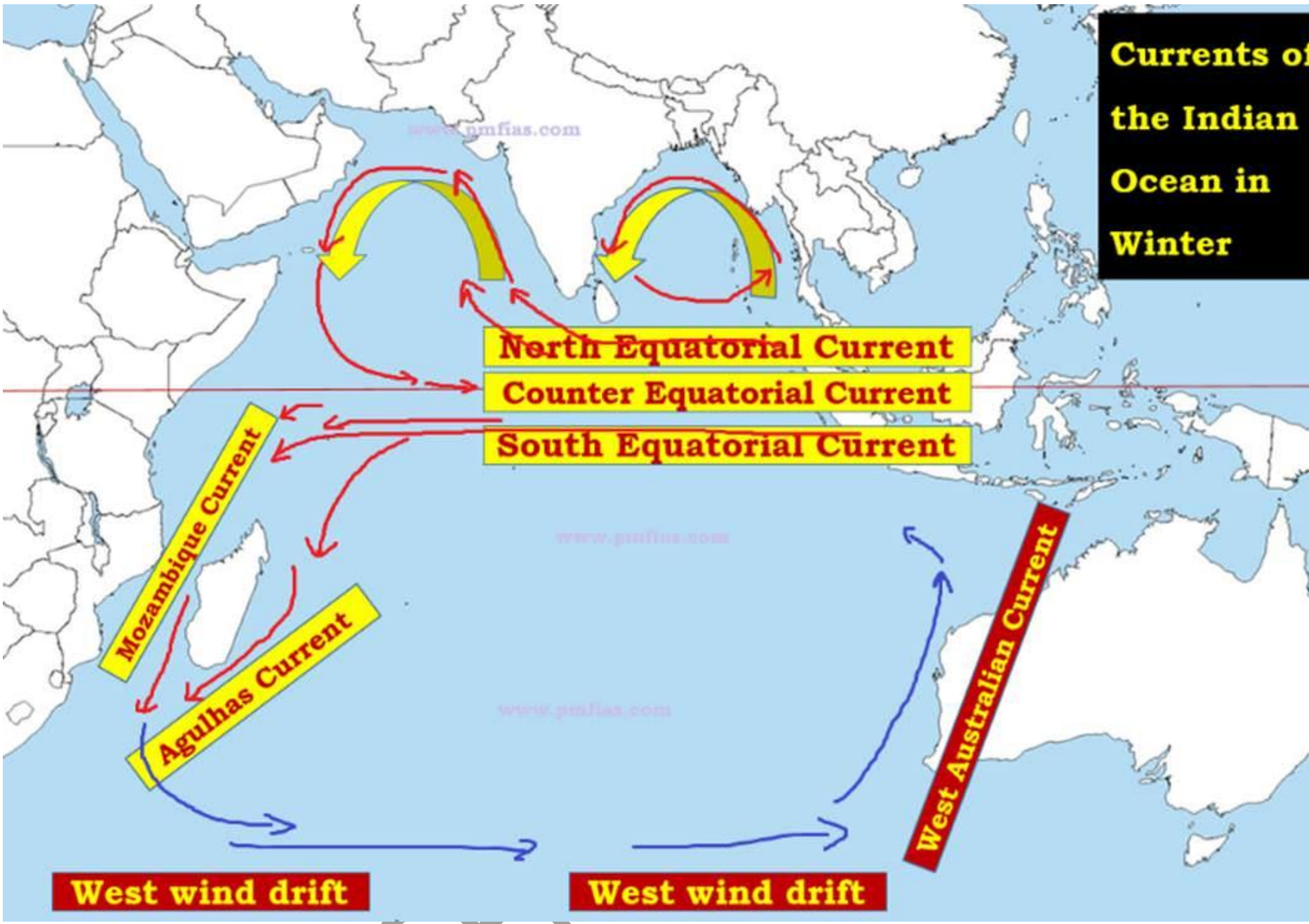
a) Bengula and Falkland
b) Canary and Humboldt
c) Agulhas and Guinea
d) Benguela and Guinea

1.8. Indian Ocean Currents

- Indian ocean is **half an ocean**, hence the behaviour 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)

1.8.1.1. 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.



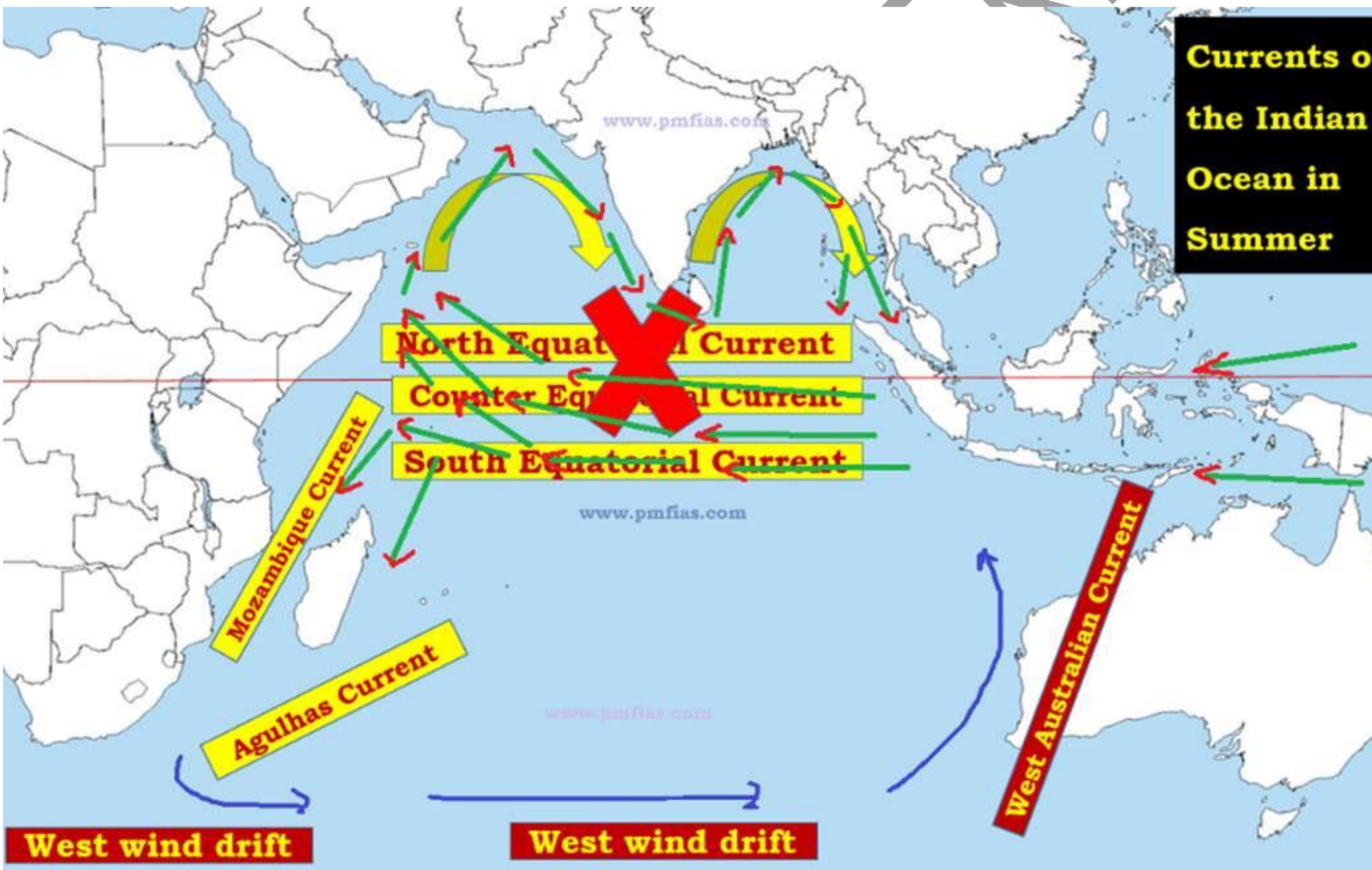
North Indian Ocean Currents

1.8.1.2. Winter Circulation

- Under the influence of **prevailing 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 centimetres.
- 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**.

1.8.1.3. 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 flow 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.



South Indian Ocean Currents

1.8.1.4. Southern Indian Ocean Currents

- 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.

1.9. Effects of Ocean Currents

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

1.9.1.1.1.1. Desert formation

- Cold ocean currents have a direct effect on **desert formation** in west coast regions of the **tropical and sub-tropical continents**.
- There is **fog,** and most of the areas are **arid due to desiccating effect (loss of moisture — fog or temperature inversion inhibits convection).**

1.9.1.1.1.2. Rains

- Warm ocean currents bring rain to coastal areas and even interiors. Example: Summer Rainfall in **British Type climate (North Atlantic Drift)**.
- 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.

1.9.1.1.1.3. 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.)

1.9.1.1.1.4. Fishing

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

1.9.1.1.1.5. Drizzle

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

1.9.1.1.1.6. Climate

- **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**.

1.9.1.1.1.7. Tropical cyclones

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

1.9.1.1.1.8. 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 kmph)**.
- 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 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)

1.10. Desert Formation and Ocean Currents

1.10.1.1.1. Mains 2013: Major hot deserts in northern hemisphere are located between 20-30 degree north and on the western side of the continents. Why?

- Major hot wind deserts 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 aridity of the hot deserts is mainly due to the effects of off-shore Trade Winds; hence they are also called **Trade Wind Deserts.**

Why between 20 – 30 degree?

- The hot deserts lie along the **Horse Latitudes or the Sub-Tropical High-Pressure Belts** where the air is descending, a condition least favourable for precipitation of any kind to take place.

Offshore winds

- The rain-bearing Trade Winds blow **off-shore** and the Westerlies that are on-shore blow outside the desert limits (outside tropics).
- Whatever winds reach the deserts **blow from cooler to warmer regions**, and their **relative humidity is lowered**, making condensation almost impossible.
- Under such conditions, every bit of moisture is evaporated.

Why on western coast?

- On the western coasts, the presence of cold currents gives rise to **mists and fogs** by chilling the on-coming air. This inhibits convection in the air (because of temperature inversion).
- 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.

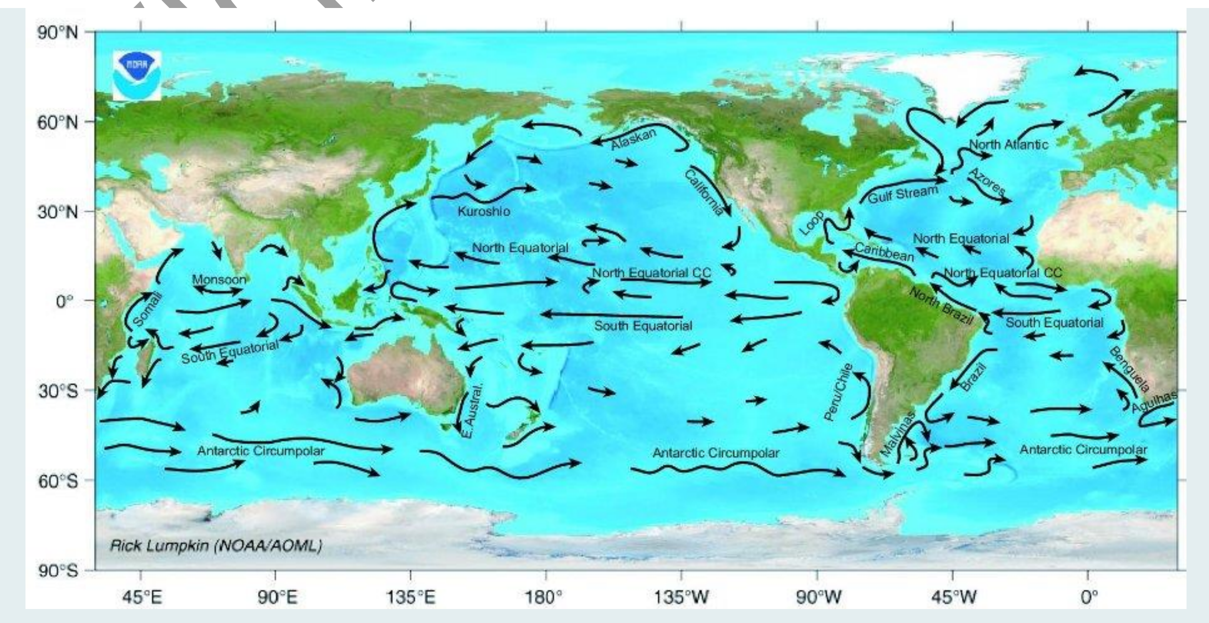
4. How does wind create all the ocean currents?

Category: Earth Science Published: July 22, 2013

Ocean currents are mostly not created by wind. While wind can play a role, often minor, in shaping surface ocean currents, it is not the main or only factor. Furthermore, wind plays virtually no role at all when it comes to deep ocean currents. The main drivers of ocean currents are as follows:

1. The Coriolis Force.

The rotation of the earth causes two main inertial forces: the centrifugal force pointing straight up (which is mostly swamped out by gravity), and the Coriolis force which points perpendicular to an object's motion. The perpendicular nature of the Coriolis force causes objects in motion to travel in great circles on the surface of the earth. Systems in the northern hemisphere circle clockwise while systems in the southern hemisphere circle counter-clockwise. The Coriolis force is very weak, so it has little effect on which way the water spirals in a sink as it drains. But when a lot of water is involved, such as in the ocean, the Coriolis force plays a large role. Because of the Coriolis force, the major ocean currents in the northern hemisphere tend to spiral clockwise and they tend to spiral counter-clockwise in the southern hemisphere. These current patterns can be seen in the image below. The Coriolis force is an inertial force that arises from the earth being in a rotating reference frame. The Coriolis force is not imaginary or fictional, but is simply inertial, meaning that it is very real in the rotating reference frame, but is not fundamental as it arises from the motion of the frame itself.



Public Domain Image, source: NOAA.

2. Density Differences.
Fluctuations in both temperature and salt content lead different regions of ocean water to have different densities. Higher temperatures, such as near the equators, cause a given mass of water to expand and therefore drop in density. Also, lower salt content causes a given mass of water to be lower in density. Gravity causes the more dense water to fall, pushing away the less dense water, which shoots sideways and rises. Giant convection loops of ocean currents form as the lighter (hotter, less salty) regions of water rise and flow to replace the heavier (colder, more salty) regions of water. The effect of density-driven currents is fundamentally a result of the interplay heating from the sun, earth's gravity, and salinity differences.

3. Tides.
Differences in the gravitational field of the moon from one location to the next causes tidal forces. Differences in the gravitational field of the sun also causes tidal forces. Tidal forces push water towards the axis connecting the earth and moon, and the axis connecting the earth and sun. The water moves in ocean currents in response to these tidal pushes, causing the well-known daily cycle of high tide and low tide.

4. Shoreline Obstruction.
Although ocean currents are not directly generated by the shoreline, they are certainly shaped by the shoreline. As the water in an ocean current moves forward under the push of the forces listed above, it inevitably runs up against the solid mass of land and is deflected along the shoreline. The above-water shoreline, as well as the shape of the ground under the water's surface (the depth contours), both affect the direction of ocean currents.

Topics: Coriolis force, density, gravitational gradient, gravity, ocean, ocean currents, salinity, temperature, tidal force, tides, water, wind

Module 15: OCEANIC DEPOSITS

Ocean deposits usually consist of unconsolidated sediments, which can come from various sources, and are deposited at the ocean floor. Thicknes of thes deposts vary greatly from one ocean to another (fig 1). Ocean deposits can be differentiated on the basis of their compostion, source, method of transit, and mode of distribution.

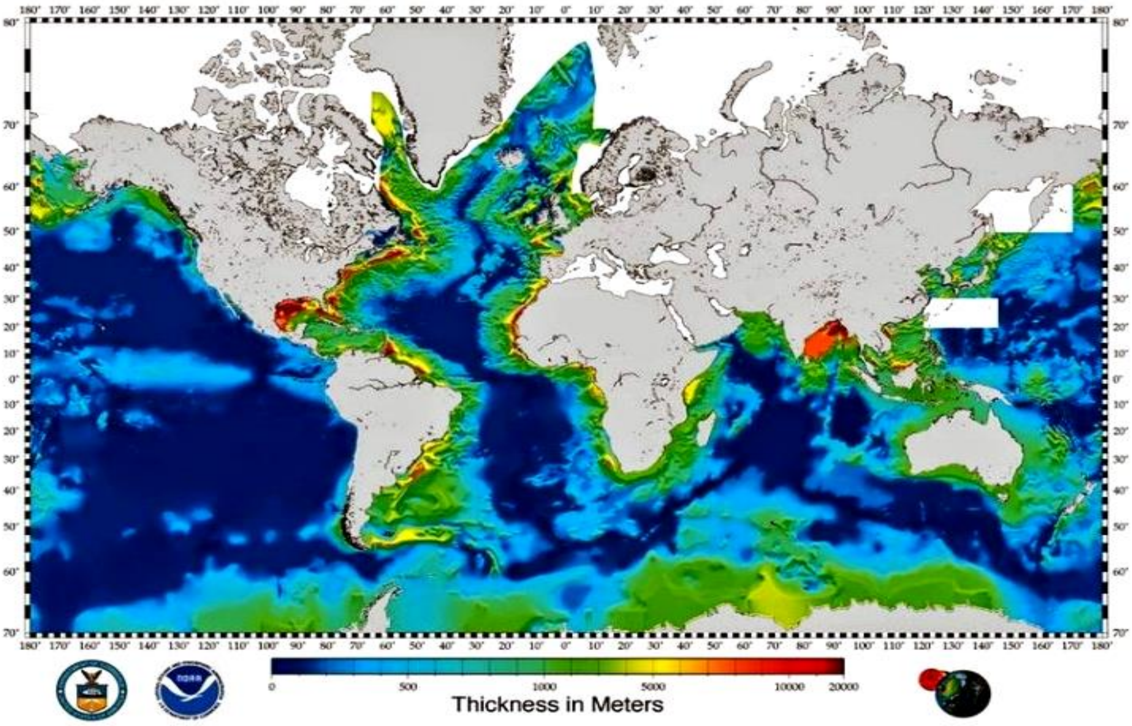


Figure 1: Sediment thickness of oceans and marginal seas of the world, source: NOAA.

The componets of ocean depostis can be transported by rivers, winds, volcanic eruptions, and marine organisms, both plants and animals can also contribute to the transporation and deposit of ocean deposits. According to the characteristics of ocean depth, ocean deposits can be classified as pelagic deposits, and terrigenous deppsits.

While terrigenoous deposits at mostly the shallower depths can include deposits of mud, sand and graval, and vocanic materials, derived from denudationof continetal rocks, pelagic deposits can consist of organic material in the form of marine plants and animals as well as inorganic material. Pelagic doposits can cover about 75.5 % of ocean areas in the form of many types of oozes in a sporadic mix in most cases with other types of ocean deposits. Of the total ocean deposits, re clay coer 31.1 % of the ocean floor (srisha P., 2017). Pelagic zone consists four major zones classified according to depth i.e. Epipelagic zone, mesopelagic zone, Bathypelagic zone and Abyssopelagic zone as shown in fig 2.

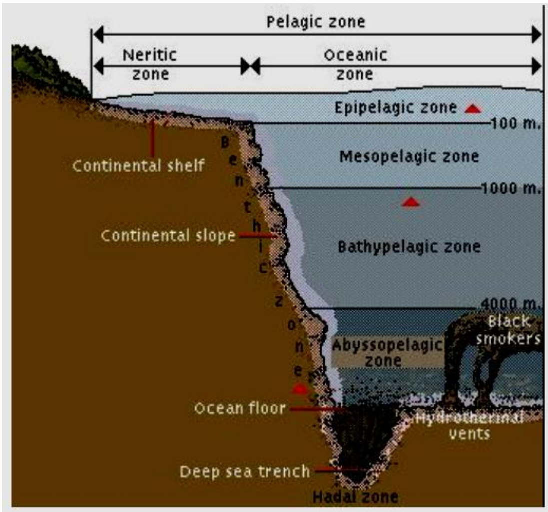


Fig 2: Pelagic zone. Source: FAO

In 1874, thomson published a preliminary repot on the nature of pelagic deposits, followed by a description by murray in 1876. This secceeded an expedition by the H.M.S. Challenger in 1872 that carried out pioneer studies of ocan deposits. //
these studies established the existence of red clays, gobigerina, pteropod, radiolarian and diatom oozes on the ocean floor. This was followed by the publication of many paers investigating the nature of deep ocean deposits. Most studes in this period were instrested in paleantological observations in analyzing oceanic deposits. Many comparisons were made etween pelagic deposits on the ocean floor and soils in terrestrial locations.

Among these observations, murray's observations were the most influential, which asserted that sediments were not necessarily located at great depths and oceanic, and deep sea ocean deposits could even be found in environments close to the shoreline. Murray's observations were populat mainly among the Anglo-americal geological diaspora, and many European scientist continued to pursue the presence of oceanic deposits in ancient mountain chains.

Since 1968, with the observations of the Glomar Challenger, a new world of findings opened for geology. The results from their observations conclusively pointed towards a spreading ocean, drifting and colliding continents, etc such that there was a good possiility that ocean deposits could be found within mountain soil.

Mountainous regions indeed were sites of two colliding continents, making them logical sites for pre-ocean deposits (H.C. Jenkyns, 2010). However, studies so far have revealed that pelagic deposits are largely conined to ocean basins, with fresh pelagic deposits no replica of distant past.

Although investigations of organic pelagic deposits of earlier periods can reveal a great deal about biodiversity in previous eras, not much is know in totality of the complete deep-ocean biodiversity. Scientific knowledge of both pelagic and benthic biodiversity is not complete, and a great deal is stidll left to be known. In the past, studies have been carried out of deep-ocean biodiversity for example in the atlantic ocean, the arabian sea, and prts of the pacific, but these studies have been carried out on a spatially and temporally limeted basis on a limited population of taxa.

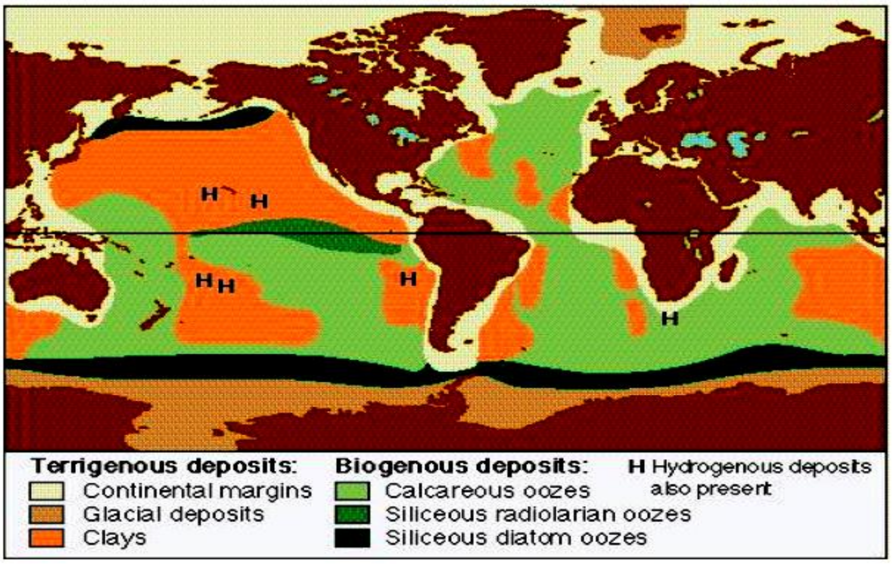


Fig : Pelagic and Terrigenous ocean deposits distribution of the world.

Introduction to Ocean Deposits:

The unconsolidated sediments, derived from various sources, deposited at the sea floors are included in ocean deposits. The study of ocean (marine) deposits includes the consideration of types of sediments, their sources, methods of their transportation, horizontal distribution, lithological successions or vertical variations in their distribution and composition etc.

The sediments derived from weathering and erosion of continental rocks are transported to the oceans by rivers, winds etc. Volcanic eruptions also provide sediments. Besides, the decay and decomposition of marine organisms (both plants and animals) also contribute sediments to ocean deposits.

Most important types of ocean deposits are: 1. Terrigenous Deposits 2. Pelagic Deposits.

There are unconsolidated sediments, deposited on the ocean floor. These are ocean deposits. They vary from location to location.

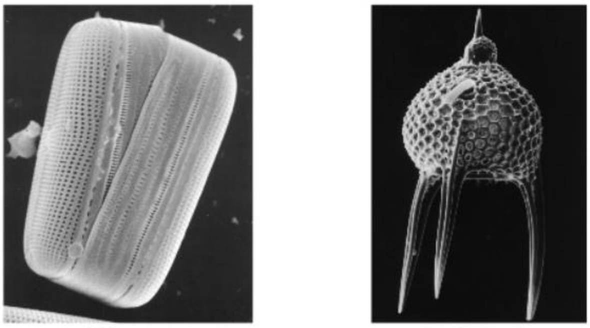
https://www.slideshare.net/daengaslam/ocean-sediments-15262057

The study of ocean deposits is important in understanding the rocks exposed on the earth's surface which were once laid under sea.

The 4 main types of sediment

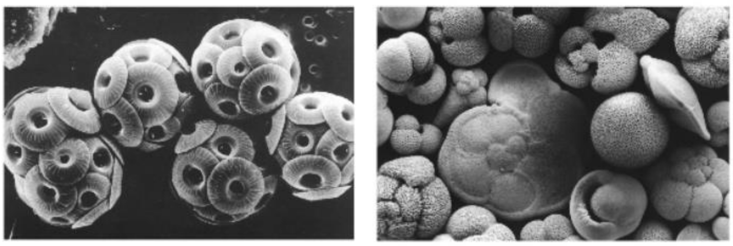
1. **Lithogenous** = composed of fragments of pre-existing rock material
2. **Biogenous** = composed of hard remains of once-living organisms
3. **Hydrogenous** = formed when dissolved materials come out of solution (precipitate)
4. **Cosmogenous** = derived from outer space

Examples of silica-secreting microscopic organisms



Diatom **Radiolarian**

Examples of calcite-secreting microscopic organisms



Coccolithophores **Foraminifers**

Definition ocean Sediments

- Ocean sediments are unconsolidated organic and inorganic particles that accumulate on the ocean floor.
- Ocean sediments originate from numerous sources
  - weathering and erosion of the continents (terrigenous/lithogenous)
  - volcanic eruptions (volcanogenous) included in terrigenous sediments.
  - biological activity (biogenous)
  - chemical processes within the oceanic crust and seawater (Hydrogenous/autigenous)
  - impacts of extra-terrestrial objects (cosmogenous)

Classification

- 1. Clasification by origin
  - a. Terrigenous - erosional products (also volcanics) composed of fragments of pre-existing rock material
  - b. Biogenous - composed of hard remains of once-living organisms. shells
  - c. Hydrogenous - formed when dissolved materials come out of solution (precipitate) (in situ precipitation). Desolved materials form as a result weathering
  - d. Cosmogenous - extraterrestrial (derived from outer space)

Percentage of Sediment type in the Ocean

Sediment type	% of all ocean floor covered
Terrigenous	~ 45%
Biogenous	~ 55%
Hydrogenous (authigenic)	<1%
Cosmogenous	very small amount

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 for upto the continental slope.

1. Terrigenous Deposits:

Terrigenous sediments are those where the ultimate source is weathering and erosion of rocks on land. The materials composing these sediments are introduced to the ocean by water, wind or ice. Terrigenous sediments are more abundant close to the continents, specifically near river mouths and in the very deep areas of the oceans. The composition of terrigenous sediments thus depends on the climate and weathering at the source region, and the distribution of these sediments by the geographic deposition of rivers and the prevailing winds. Rivers and glaciers carry large particles and deposit 1010 tons annually, while the winds deposit 108 tons of much smaller particles. These sediments are most abundant on continental margins where rivers come in (Atlantic > Pacific). The smaller, wind blown terrigenous particles, are present everywhere in the oceans and they are the major component of a large fraction of the sediment in the deep Pacific basin, mostly because the biogenic components are not preserved there. Thus, terrigenous and hydrogenous minerals are the dominant components of red clays. This does not mean that the input of this material is larger there but rather that there is nothing else to dilute it with. Terrigenous sediments enclose information about river fluxes, sources of the weathered material (provenance), weathering processes on land, wind stress and direction, as well as glacial extent and glaciers location (ice rafted debris).

Volcanic sediments are composed of minerals brought into the ocean mostly by wind, as dust and ash from volcanic eruptions. They are typically in the size range of 1 m. Their abundance gives information about periods and locations of intensive volcanic activity. These sediments are more abundant close to volcanic islands but also globally distributed after big eruptions. These deposits are easy to date by radioactive age determination and because of their global and instantaneous distribution can be used for global correlation.

Cosmogenic particles are those that arrive from outer space and survive the Earth's atmosphere to enter the sedimentary record. About 4-6 x104 tons of these particles accumulate each year, they range in size from 0.1 to 1mm and have a typical spherule shape. They have distinct geochemical signatures (high 3 He, Ir, Os and Os isotopes and organic compounds not typical to Earth) and provide information about possible changes in the rate of cosmogenic bombardment as well as catastrophic impacts (K-T). They could also be a mean of estimating sedimentation rate if we assume constant accumulation.

Authigenic components are oceanic inorganic minerals that precipitate directly from the seawater, either in the water column or in the sediment after burial. These minerals make up only a small fraction of deep-sea sediments today, but in special environments and certain geological times, they comprise the bulk of the sedimentary sequence.

These include **evaporites,** which are sediments that are deposited as a result of evaporation of water and usually occur in restricted basins and lagoons on the shelf where evaporation exceeds precipitation and flushing in of water. This includes the minerals anhydrite, gypsum, halite, dolomite and more. These sediments enclose information about the climate and basin configuration conditions at the location and time of their formation and also carry valuable information about the chemical makeup of seawater. For example, when anhydrite precipitates, the sulfate forming this mineral comes from seawater and has the same isotopic composition as seawater sulfate, so we get a record of the seawater S isotopic composition.

Another group of important authigenic components are **Hydrogenous** Fe-Mn oxyhydroxides: These minerals usually form as coating on existing minerals, but also occur as nodules and crusts. The Fe-Mn oxides and hydroxides co-precipitate and scavenge trace metals from seawater and thus could reveal chemical information of the ocean.

Biogenic Sediments are one of the most important constituents of marine sediments. As the name implies, these form directly or indirectly through biological activity. They are made of a variety of delicate and intricate structures mostly of skeletal remains of marine phytoplankton and zooplankton. The life span of most of these organisms is on the order of weeks, so there is a slow continuous "rain" of their remains down through the water column to build successive layers of sediment. The distribution of these sediments would depend on the abundance of organisms precipitating these phases and dissolution at depth (e.g. preseration).

The most important biogenic minerals are carbonates and biogenic silica (opal) Carbonate Sediments are composed principally of skeletal remains of calcite or aragonite secreting organisms.

Coccolithophores are phytoplankton covered with a test made of plates of calcite, 10μm in size that are called coccoliths; the organisms shed these plates throughout their life time. An organic membrane covers the coccoliths and this inhibits their dissolution. The coccoliths are also referred to as "nano fossils"; nano means dwarf in Greek. Coccolithophores are abundant in central gyres where productivity is relatively low.

Foraminifera are protists that produce calcite exoskeletons, or tests. They can be planktonic (float on the surface) or benthic (live at the bottom) and range in size from ~ 30 m to 1mm. The spiny ones have symbionts and live in the photic zone where light is available; these spiny species are very delicate and more soluble. Non-spiny forms are better preserved in sediments.

Pteropods are planktonic gastropods, mollusks that are restricted to the tropics and subtropics and have aragonitic shells. Usually not preserved well and cannot be found in sediments deeper than ~2000m.

Silica Secreting Organisms include:

Diatoms which are unicellular alga a few micron to 200 micron in size. They secrete frustules from amorphous hydrated silica (opal). They are abundant in high productivity areas such as coastal upwelling, equatorial regions and high latitude areas. There are some benthic diatoms that are restricted to shallow waters.

Radiolarians are large zooplankton in the range of 50- 300 micron. They secrete very intricate shells structures. They are usually abundant in low latitudes.

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).

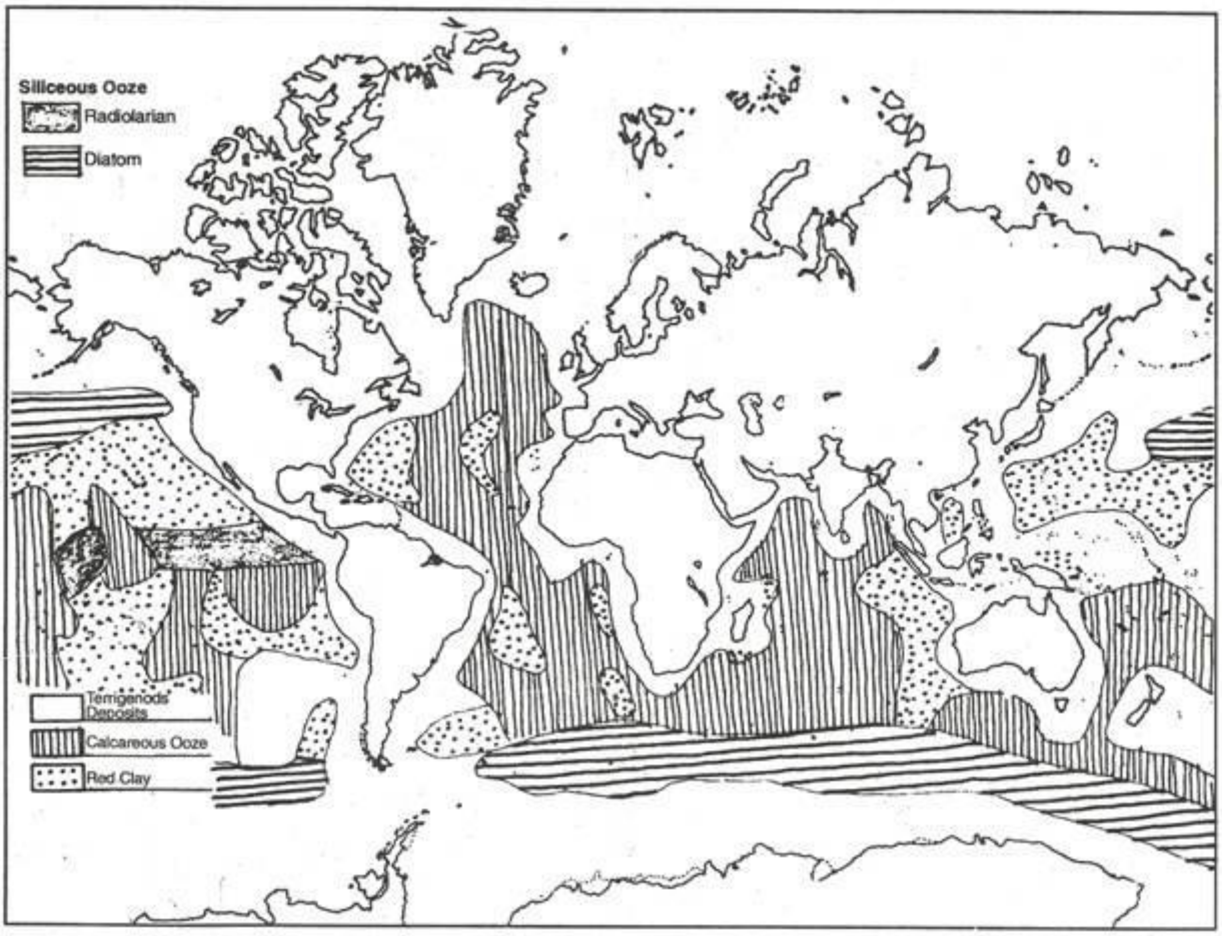


Fig. 3.13 Map showing the distribution of various types of ocean deposits.

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. Murray has classified the mud deposits into blue, green and red types, based on the colour of constituents. 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 volcanic 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.

2. 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).

CLASSIFICATION OF OCEANIC DEPOSITS:

Ocean deposits are classified on different bases e.g.:

(1) On the basis of location,

(2) On the basis of depth,

(3) On the basis of the origin of sediments etc.

1. On the Basis of Location:

This classification is based on typical locations of particular marine sediment. Though several scientists have attempted to classify ocean deposits on the basis of their locations, the classifications of Sir John Murray and J.T. Jenkins are widely acclaimed.

(i) Classification of Murray:

Sir John Murray has classified the ocean deposits into two broad categories viz.:

(a) terrigenous deposits and

(b) pelagic deposits.

Terrigenous deposits are found mainly on the continental shelves and slopes whereas pelagic deposits predominate on the deep sea floor. Terrigenous deposits are composed of coarser materials and are derived from the continents through weathering and erosional processes and are transported to the oceans by various agencies.

Their colour may be blue, yellow, grey or red. Pelagic deposits consist of fine materials formed of skeletons and shells of marine organisms and a few inorganic substances. They are generally blue, grey or red in colour.

(ii) Classification of Jenkins:

Jenkins has divided marine deposits into three groups viz.:

(a) Deep sea deposits,

(b) Shallow water deposits, and

(c) Littoral deposits.

The following is the detailed classification of Jenkins:

(A) Pelagic deposits:

(1) Red clay,

(2) Radiolarian ooze,

(3) Diatom ooze,

(4) Globigerina ooze, and

(5) Pteropod ooze.

(B) Terrigenous deposits:

(1) Blue mud,

(2) Red mud,

(3) Green mud,
(4) Coral mud,
(5) Volcanic mud,
(6) Gravel, and
(7) Sand.

2. On the Basis of Depth:

(A) Deep sea deposits (Below 100 fathoms):

(a) Pelagic Deposits:

(1) Red clay,
(2) Radiolarian ooze,
(3) Diatom ooze,
(4) Globigerina ooze, and
(5) Pteropod ooze.

(b) Terrigenous Deposits:

(1) Blue mud,
(2) Red mud,
(3) Green mud,
(4) Coral mud, and
(5) Volcanic mud.

(B) Shallow sea deposits (between low tide water and 100 fathoms):

(1) Gravels,
(2) Sands, and
(3) Mud.

(c) Littoral deposits (Between high and low tide water):

(1) Gravels,
(2) Sands,
(3) Mud.

2. General Classification:

(1) Terrigenous Deposits:

i. Littoral deposits,
ii. Shallow water deposits, and
iii. Terrigenous mud.

(2) Neritic Deposits:

i. Shallow water neritic deposits,
ii. Deep sea water neritic deposits, and
iii. Pelagic deposits.

3. Classification on the Basis of Origin of Sediments:

(1) Littoral deposits (derived from land)):

(i) Shore deposits.

(ii) Shelf deposits.

(2) Hemipclagic deposits (Partly from land and partly from marine origin):

(i) Green mud.

(ii) Volcanic mud.

(iii) Coral mud.

(3) Eupelagic deposits (Of marine and cosmic origin):

(i) Red clay.

(ii) Radiolarian ooze.

(iii) Globigerina ooze.

(iv) Pteropod ooze.

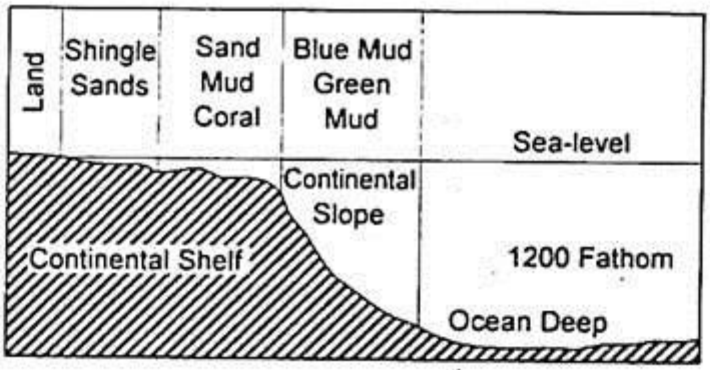


Fig. 27.1 : General distribution of marine sediments.

Distribution of Ocean Deposits:

Terrigenous Deposits:

Terrigenous deposits include gravels, sands, muds, volcanic materials etc. which are derived through weathering and erosion of continental rocks by various denudational processes. There is marked gradation of these sediments when they are deposited in the oceans. The sequence of these materials from the coast towards the sea is gravel, sand, silt, clay and mud. The ocean currents and waves very often disturb the gradation and sequence of sediments.

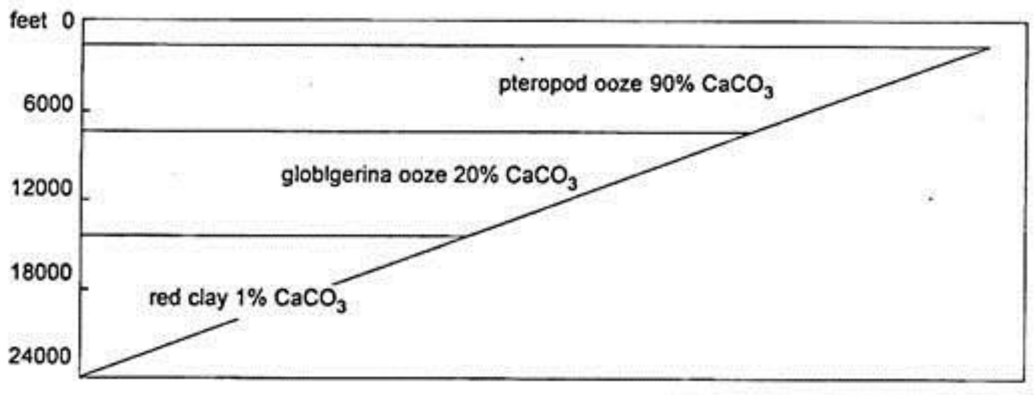


Fig. 27.2 : General vertical distribution of ocean deposits.

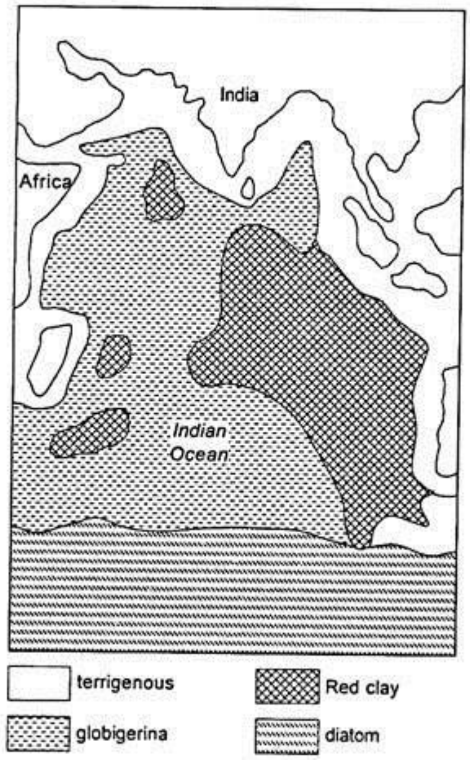


Fig. 27.3 :Horizontal distribution of marisne deposits in the Indian Ocean.

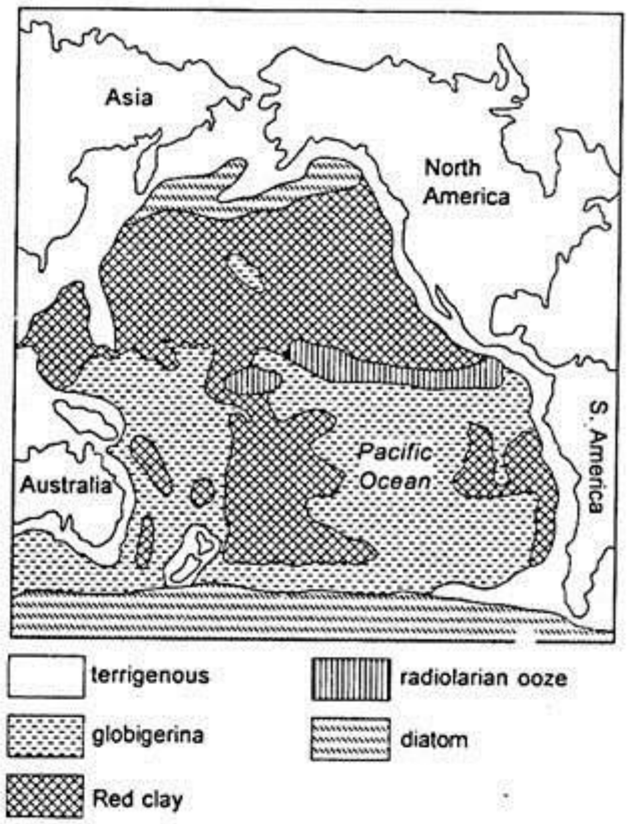


Fig. 27.4 : Horizontal distribution of marine deposits in the Pacific Ocean.

Terrigenous deposits are classified into 3 categories on the basis of location and depth:
(1) Littoral deposits are generally found on the continental shelves mainly near the coastal margins upto the depth of 100 fathoms (600 feet) but they have been also traced upto the depth of 1000m-2000m. Littoral deposits consist of gravels, sands, silt, clays and muds.
(2) Shallow water deposits include terrigenous sediments deposited between low tide water and 100- fathom depth. These deposits consist of gravels, sands, silt and clays of varying proportions. Sea waves and tidal waves help in the gradation and sorting of sediments but landslides, slumping, strong storm waves, and storms sometimes disturb the vertical stratification of sediments.
(3) Deep water deposits include the sediments deposited below the depth of 100 fathoms. There is marked gradation of sediments in vertical succession where the sequence of sediments with increasing depths is blue mud, red mud, green mud, coral mud and volcanic mud.

Pelagic Deposits:

Pelagic deposits consisting of remains of marine plants and animals in the form of different types of oozes cover about 75.5 per cent of the ocean areas. Pteropod, diatom and radiolarian oozes cover 0.4, 6.4 and 3.4 per cent areas of all the oceanic deposits respectively. Red clay constitutes 31.1 per cent of the total ocean deposits.

Pteropod oozes are found over an area of 12,90,000 km . Globigerina oozes cover larger areas in the Pacific (64.5 million km^2), the Atlantic (37.9 million km^2) and the Indian (31.4 million km^2) oceans (figs. 27.3, 4 and 5). Radiolarian oozes are found over an area of 5.16 million km^2 in the Pacific and Indian oceans, Diatom oozes arc spread over an area of 1,03,000 km^2 in the North Pacific Ocean and 27.6 million km^2 in the southern oceans. Red clay is distributed over an area of 129 million km^2 of all the oceans.

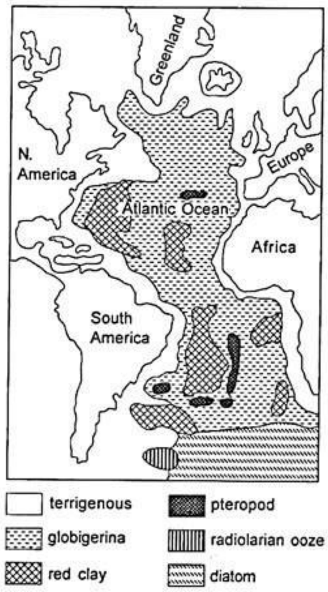


Fig. 27.5 : Horizontal distribution of marine depsoits in the Atlantic Ocean.

Philippi has described a vertical stratification of different pelagic sediments wherein the sequence from top to the bottom includes pteropod ooze, globigerina ooze, radiolarian ooze, diatom ooze and red clay.

It is apparent from the figures that terrigenous deposits are found along the coasts mainly on continental shelves but they cover greater extent near the East Indies, in the North Pacific and along the Labrador coast. Globigerina ooze, red clay and diatom ooze dominate in the western, eastern and southern parts of the Indian Ocean whereas it contains maximum areal extent in the Pacific Ocean.

- Ocean deposits are unconsolidated sediments deposited on the ocean floor.
- They are broadly divided into two types —
  1. the **terrigenous deposits** (deposits derived from land; found mainly on the continental shelves and slopes), and
  2. the **pelagic deposits** (found over deep sea plains and the deeps).

x. Terrigenous Deposits

- They are **mainly inorganic deposits** (compounds not containing carbon) derived from disintegrated rock material (due to weathering and water erosion).
- The proportion of organic matter (in the form of shells, corals and skeletons) is quite negligible.
- The disintegrated rock material is carried from land to the sea mainly by running water.
- The terrigenous deposits are found mainly on the **continental shelves and slopes**.
- Except for fine volcanic ash, little terrigenous material is carried on to the sea surface.

xi. Pelagic Deposits

- Pelagic deposits cover nearly 75% of the total sea floor.
- The pelagic deposits consist of both organic (remains of plants and animals) and inorganic material.
- Organic material is in the form of liquid mud called **ooze** which contains remnants of shells and skeletons.
- Inorganic material is in the form of red clay which is of volcanic origin.
- The chief constituents of red clay are silicon and aluminium dioxide.
- The red clay is the most widely spread pelagic deposit of the sea floor.
- The red clay covers more than half of the Pacific floor.

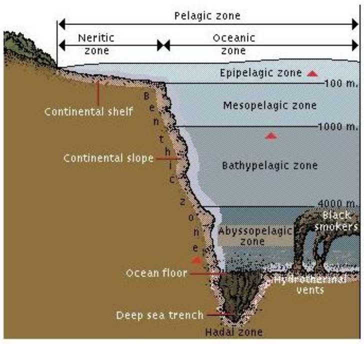


Fig. 2: Pelagic Zone

Source: FAO

5. Geography Optional Notes: Oceanic Deposits Calssification

BY SOMESH UPADHYAY · 25TH JULY 2017

The classification of oceanic deposits can be done on the basis of Source, Sediments and Location

5.1 A. Source based Classification of Oceanic Deposits

1. Terrigenous/**Lithogenous** (material eroded from land)
2. Hydrogenous (e.g. Carbonite)
3. **Biogenous** (Siliceous, Calcareous)
4. Cosmogenous (e.g. meteorite)
5. Vulcanous
6. Inorganic precipitate (from Air)

5.2 B. Sediment based Classification of Oceanic Deposits

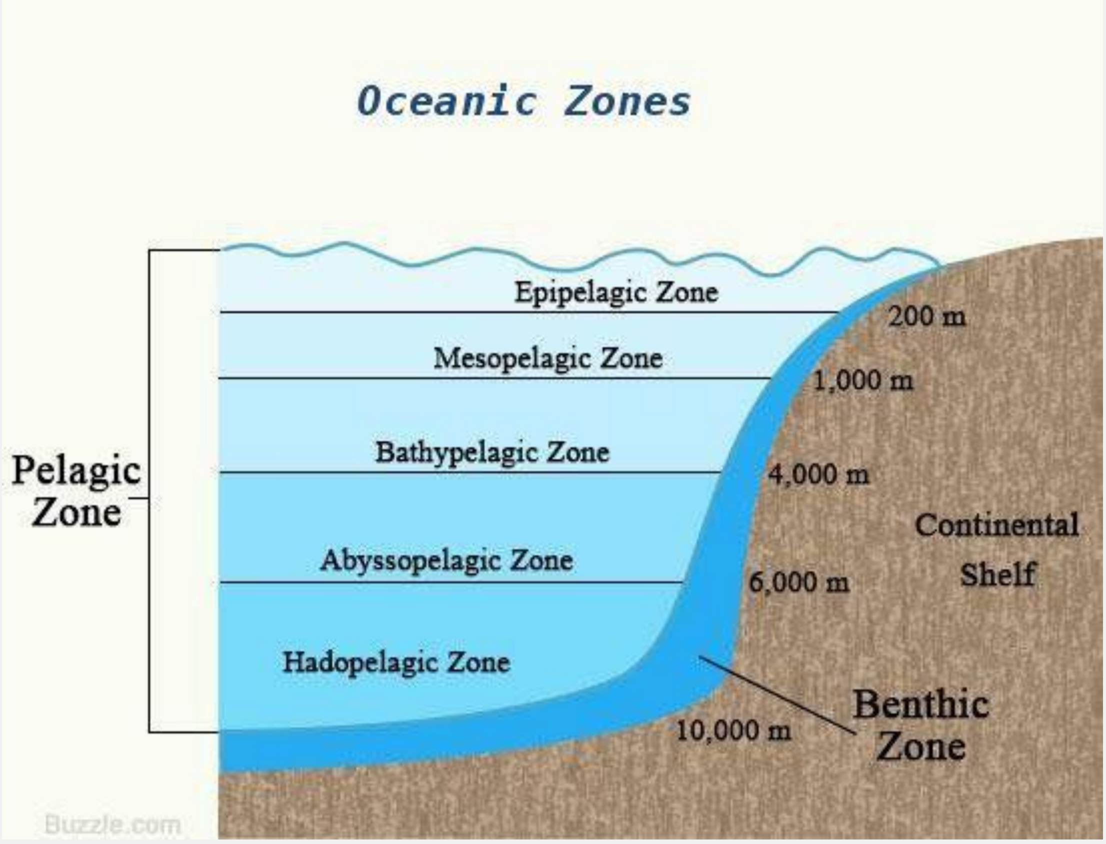
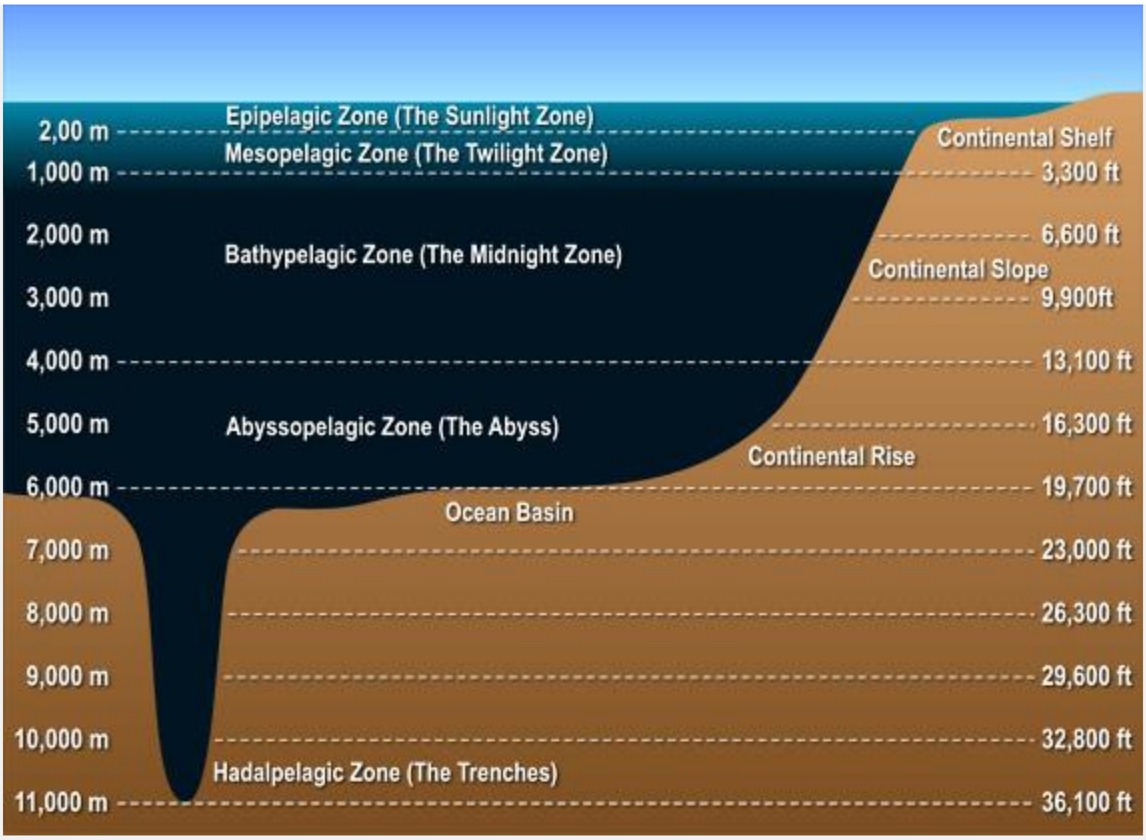


Image Source: Buzzle.com

1. Pelagic (open sea, not close to the shore)
2. Littoral (close to the shore)
3. Hemipelagic (between littoral and pelagic)
4. Eupelagic (uppermost part of the oceanic zone, lying above the mesopelagic zone, that receives enough sunlight to allow photosynthesis)

5.3 C. Location based Classification of Oceanic Deposits

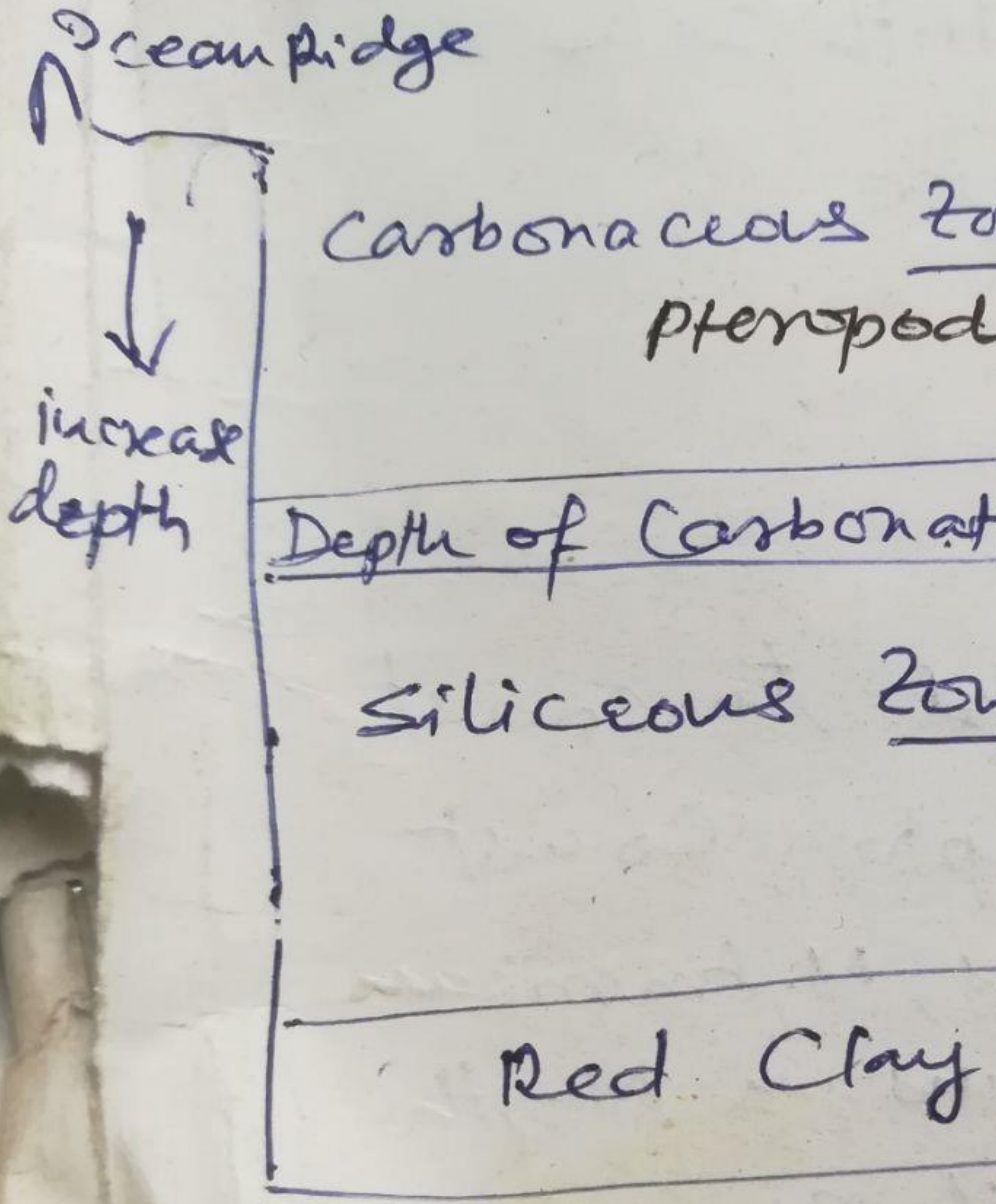
1. Continental
   - Littoral (land)
   - Shallow Waters (1000 fathoms depth)
   - Terrigenous (>1000 fathom depth)
2. Neritic (Shallow Sea)
3. Pelagic (Deep Sea)



Ocean Layers: Oceanic Zones

Lithogenous Deposits

- Depth of deposit is according to size
- Continental shelf has **boulders**
- followed by **gravel, sand, silt, clay** and **mud**
- **Mud** can be of four types:
  - Red Mud: iron oxides
  - Blue Mud: Iron + Sulfur
  - Green Mud: (Blue mud + Sea Water), has potassium silicate
  - Coral mud: coral reefs derivative



Depth profile of

Depth Profile of Biogenous Deposits

Biogenous Deposits

- These are the oceanic deposits derived from dead remains of living organisms. It can be classified into
  1. **Siliceous Ooze**
     - Diatoms : mostly phytoplanktons
     - Radiolarians: Single celled Protozoans
     - Most abundant in the Pacific Ocean
  2. **Calcareous Ooze**
     - Pteropods: marine molluscs, abundant in Indian and Atlantic Oceans
     - Globigerina: Protozoans, abundant in Pacific
     - Coccolithophores

Google the terms to understand them well enough and practice the diagrams given along with this article. These are the basics of Oceanography and must be at your fingertips. You can refer to Savindra Singh for more.

b. Mineral Resources

- Both metallic and non-metallic resources are found in seas.
- Most of these minerals are carried from land to sea by running water.
- The remaining are formed from to undersea volcanism and detritus (leftover parts) of marine organisms.
- At present, mining of only a handful of marine mineral resources is economically viable.
- Among them are offshore oil and natural gas, extraction of sodium chloride, salts of magnesium and bromine, etc.

i. Mineral deposits found on continental shelves and slopes

- The surface deposits on the continental shelves and slopes are found mixed with sand.
- Sands are mined to extract calcium carbonate along the Bahamas coast.

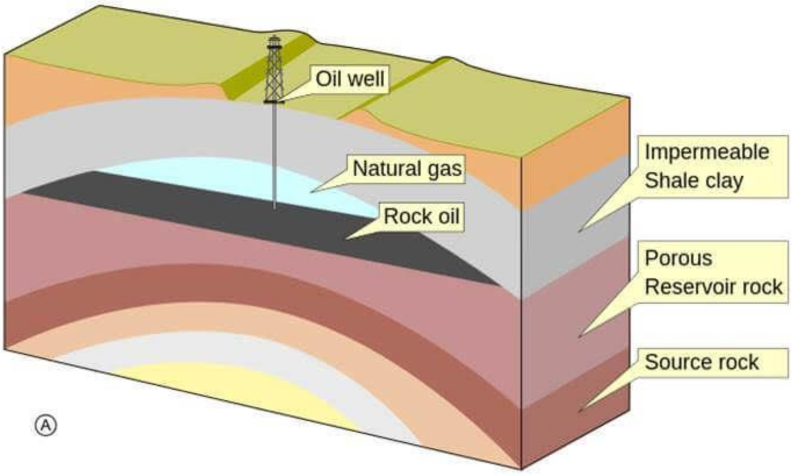
- Coral sands are mined in Hawaii and Fiji for calcium carbonate.

1. Marine Placer deposits

- A placer deposit is an accumulation of valuable **heavy minerals** that have been weathered and eroded from their source rocks.
- As a result of their high density, placer minerals **accumulate just a few tens of kilometres away** from their source rocks.
- Marine placers deposits accumulate on the continual shelves very close to the shoreline.
- The most economically important of placer minerals are **cassiterite (ore of tin), ilmenite (titanium), rutile (titanium), zircon (zirconium), chromite (chromium), monazite (thorium), magnetite (iron), gold and diamonds**.
- The beach sands of western India, coastal Brazil, Australia have zircon, monazite (**thorium is extracted form monazite sands found across the Kerala coast**) and rutile.
- **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**.
- Placer diamonds are mainly mined in shelf sediments along the west coast of South Africa and Namibia.
- Gold placers occur along the coast of Alaska on the East Pacific shelf.
- The **tin ore, cassiterite**, a residue of granite weathering, occurs in the shelf of South East Asia.

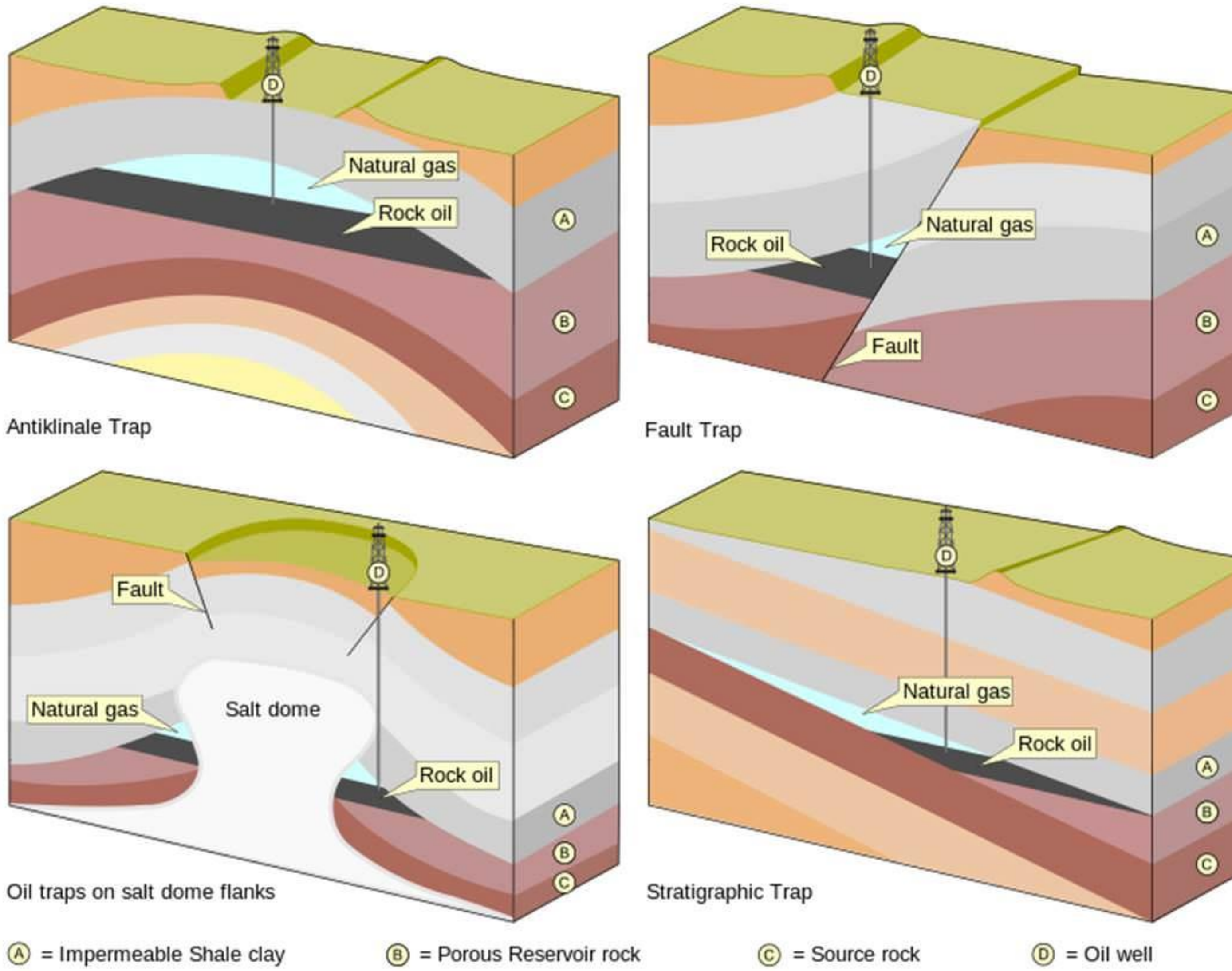
2. Marine hydrocarbon deposits

- Generally, large quantities of hydrocarbons can be formed only at depths within **organic-rich layers greater than 1,000 - 2,000 meters**.
- Formation of exploitable reservoirs of hydrocarbons requires migration (from their source rocks) to **geological traps** comprising a **porous reservoir rocks** and **overlain by an impermeable horizon**.



Anticline trap (MagentaGreen, Wikipedia Commons)

- Common geological traps for hydrocarbons include **shales, salt domes (evaporites; also rich in sulphur), and anticlinal folds of permeable and non-permeable strata**.
- In addition to liquid hydrocarbons, natural gas is also common.



Oil and Gas traps (MagentaGreen, Wikipedia Commons)

- The estimated reserves of oil worldwide at the beginning of the 21st Century are about one trillion barrels.
- Of this amount, about 252 billion barrels (**25%**) lie in marine environments.
- Similarly, the total worldwide resources of natural gas are estimated at about 4,000 trillion cubic feet, of which about 26 per cent are marine.
- These reserves of oil and gas are located as subsurface deposits almost exclusively on the **continental shelves**.
- The abyssal plains probably contain insufficient thickness of sediments (less than 1 km) to yield hydrocarbon accumulations.

- Of the twenty-five largest offshore production fields, eight are in the Persian Gulf and eight others are in the **North Sea** (**here hydrocarbons are available at a shallow depth**).
- The remaining ones are located in the Gulf of Mexico, East Asia (South China Sea), South Asia, etc.
- The western coast of India has shown promising reserves.
- Besides oil, submerged coal deposits are to be found in the **coast of Maharashtra in India**.

a. Challenges in harnessing marine hydrocarbon resources

- The cost of production from deep marine environments is economically unviable considering the present demand.
- Gas and oil exploration increase the risk of marine pollution from accidental oil spills. Existing response technologies are inadequate to contain and recover spills.

3. Marine phosphorite deposits

- Phosphorites are natural compounds containing **phosphate (used in the production of fertilizers)**.
- They are found in shallow waters and in the form of nodules on the **continental shelves and slopes**.
- At present, no offshore deposits are being mined because of the availability of non-marine phosphates.

ii. Mineral deposits found on deep sea floor

- The deep sea has two main types of mineral deposits of economic importance: **manganese nodules (also called as polymetallic nodules)** and **metalliferous sediments**.

1. Marine manganese nodules (Polymetallic nodules) and crusts

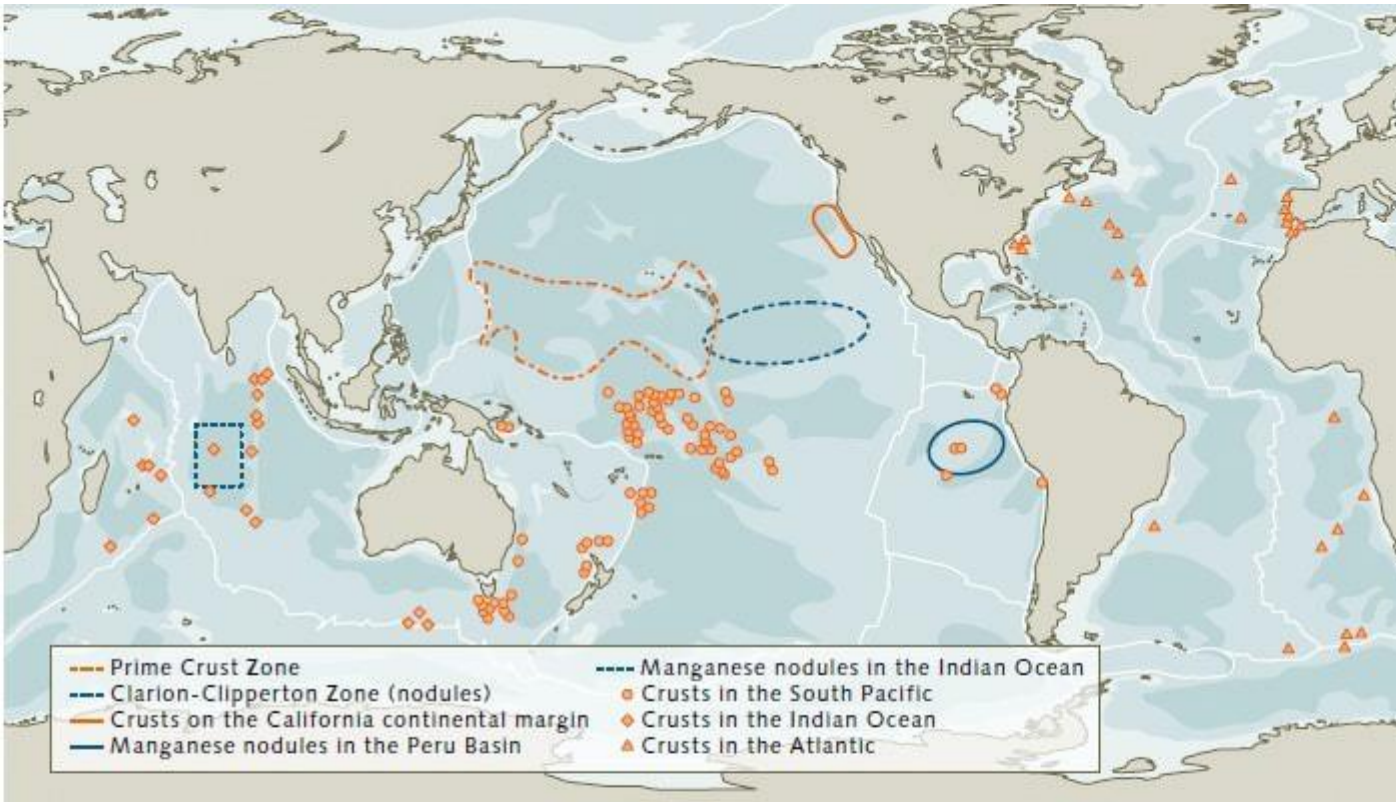
- Manganese nodules are concentrations of **iron and manganese oxides**, that can contain economically valuable concentrations of **manganese (~30%), nickel (1.25-1.5%), copper (~1%) and cobalt (~0.25%)**.
- Other constituents include iron (6%), silicon (5%) and aluminium (3%).
- They are thought to have formed from the precipitation of metals from seawater, hot springs associated with volcanic activity and metal hydroxides through the activity of microorganisms.
- Their abundance, composition, and their occurrence as loose material lying on the surface of the seabed make nodules potentially attractive to future mining.
- Manganese-rich crusts, similar in composition to the nodules, occur on rocky outcrops.
- The top ten countries that have the greatest resource potential of nodules and crusts are the United States of America, Madagascar, Brazil, Antarctica, Argentina, Japan, South Africa, Canada and India.
- Papua New Guinea is one of the few places where nodules were located in shallow waters.
- However, the expense of bringing the ore up to the surface proved to be expensive.

a. Central Indian Ocean Basin (CIOB)

- Manganese nodules in Indian Ocean cover a large area, over 10 million sq. km.
- Large areas in the basins east of the Central Indian Ridge (ridge along the Reunion Hotspot) contains nodules with a **high percentage of manganese, nickel and copper**.
- India has exclusive rights to explore polymetallic nodules from seabed in Central Indian Ocean Basin (CIOB).
- These rights are over 75000 sq. km of area in international waters allocated by International Seabed Authority for developmental activities for polymetallic nodules.

b. Challenges

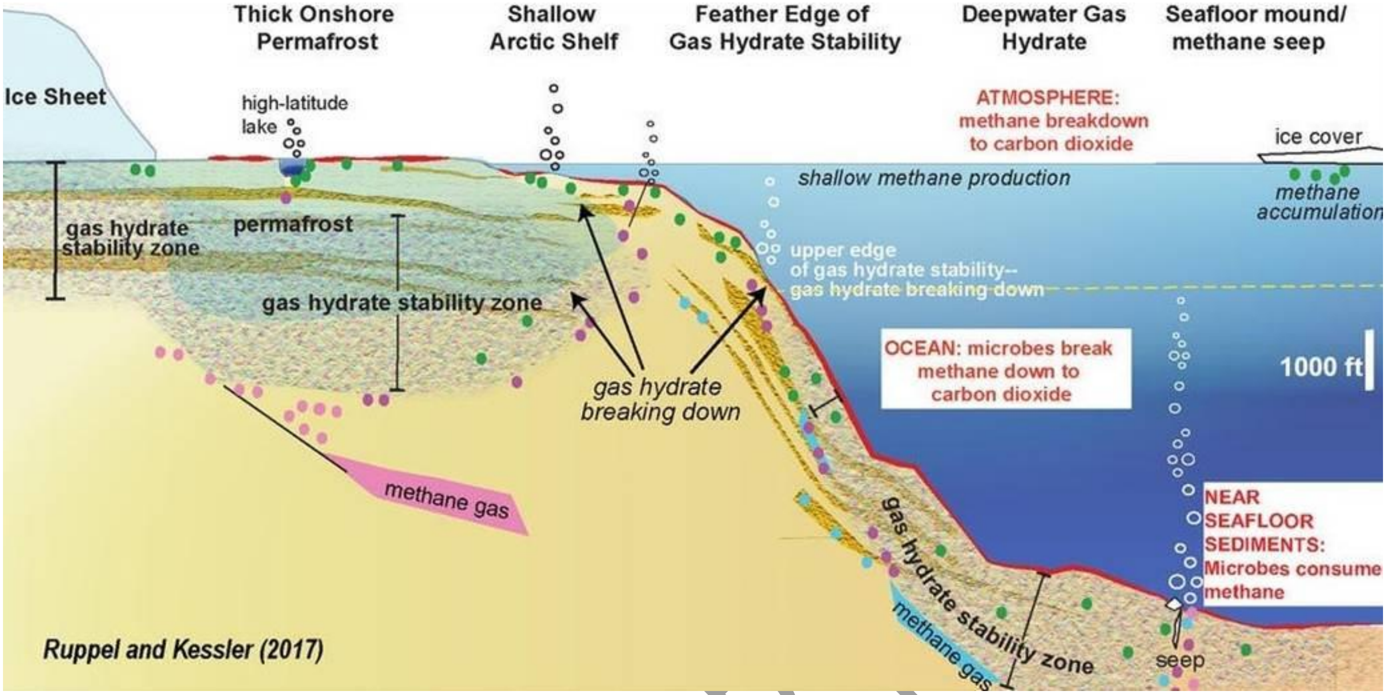
- Difficulty and expense of developing and operating mining technology that could economically remove the nodules from depths of five or six kilometres.
- Continuing availability of the key minerals from land-based sources like **nickel** at market prices.
- Mining is not economically viable for the next two decades.



Locations of known polymetallic nodules. From World Ocean Review 3, (2014) (Source)

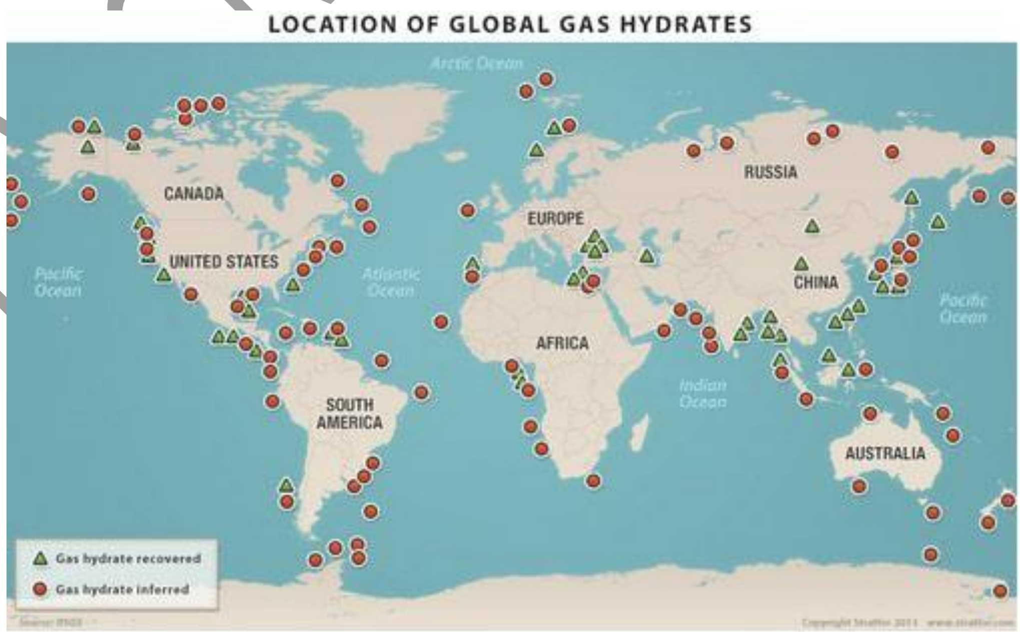
2. Marine gas hydrate deposits

- Gas hydrate is an icy crystalline compound located at great ocean depths and in shallow polar waters.
- It is composed of gas molecules, normally **methane**, encaged within water molecules.
- At great ocean depths due to cold temperatures and high ocean pressure gas hydrate remain **solid**.
- The source of the dissolved gas is from the breakdown of organic matter trapped within marine sediment.
- Hence, gas hydrate deposits are likely to occur everywhere the seafloor exceeds 500 m (or 300 m in high latitudes), and where there is a source of unoxidsed organic carbon in marine sediments.



Gas Hydrate deposits (Source)

- On dissociation at standard atmospheric pressure, gas hydrate yields approximately 164 times its own volume of methane gas.
- Gas hydrates are estimated to **hold many times more methane than presently exists in the atmosphere and up to twice the amount of energy of all fossil carbon-based fuels combined**.
- Gas hydrates are known from the Atlantic and Pacific margins of both North and South America, especially at equatorial latitudes.



Global gas hydrate deposits

a. Challenges in economic exploitation of gas hydrate deposits

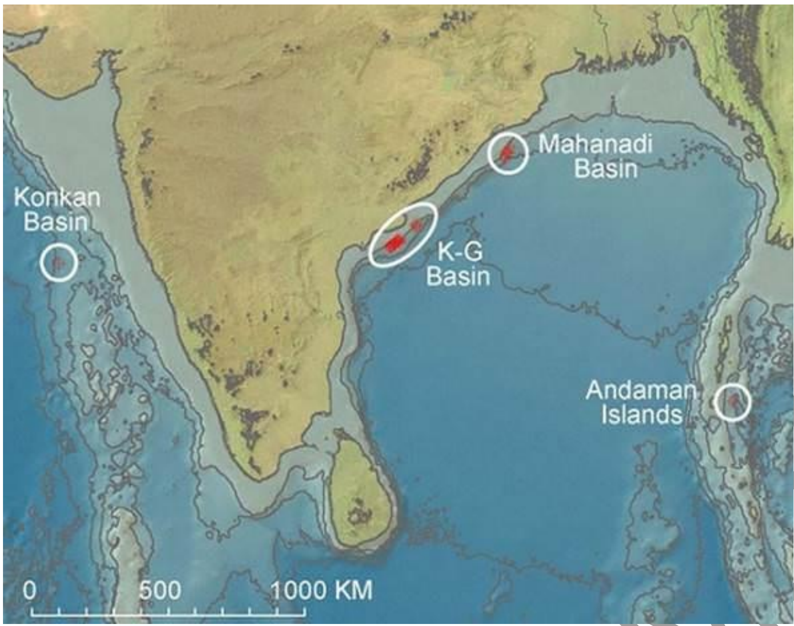
- Harnessing methane from gas hydrates is extremely challenging as they are stored deep in the ocean.
- Methane hydrates break at higher temperatures and lower pressures, presenting a challenge in the mining.

i. Methane is a greenhouse gas that traps heat twenty times more proficiently than carbon dioxide

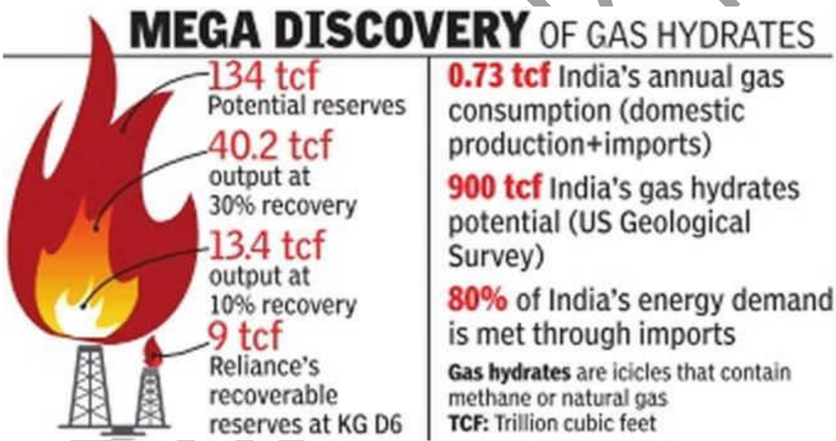
- Gas hydrate reservoirs are extremely sensitive to climate change.
- They can catastrophically accentuate global warming by releasing methane.
- Gas hydrates break into smaller pieces and float upwards.
- Once they hit warmer waters and lower pressures, they break down into methane gas.
- The driving force behind the release of methane gas is the warming of oceans worldwide.
- Mining could unlock excess methane into atmosphere.

b. Natural gas hydrate in North Indian Ocean

- 2016: ONGC discovered large, highly enriched accumulations of natural gas hydrate in the Bay of Bengal.
- ONGC plans to start pilot production from its discovery from 2017.



Accumulations of natural gas hydrate in North Indian Ocean



Source

3. Marine Polymetallic sulphides

- Deep seabed Poly-Metallic Sulphides (PMS) containing **iron, copper, zinc, silver, gold, platinum** in variable constitutions.
- They are formed due to the **precipitation of hot fluids from upwelling hot magma** discharged along the mid-ocean ridges.
- Considerable interest has been sparked by the discovery of **polymetallic sulphides in Western Indian Ocean**.
- India has received a 15 years contract from International Seabed Authority (ISA) for exploration of PMS in the area of 10,000 sq km in parts of Central and South - West Indian Ridges (SWIR).

- In the SWIR, PMS 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**.

4. Marine evaporite deposits

- Marine evaporites, formed by evaporation of sea water in geologic basins comprise mainly anhydrite and gypsum (calcium sulphates), sodium and magnesium salts and potash-bearing minerals.
- Rock salt cause upward protrusion forming salt domes, plugs, and other diapiric structures (salt domes explained in Volcanism).
- They can form structures in the sedimentary strata that are favourable for the accumulation of hydrocarbons.
- However, rock salts are abundantly available on land, and there is little value in marine deposits.

c. Energy Resources

i. 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 tides.

ii. Ocean Thermal Energy Conversion (OTEC)

- 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.
- Belgium and Cuba are producing power in this way.
- 2008: An experimental 1MW plant at Kulasekarapattinam in Tamil Nadu was set up.

iii. Geothermal Energy

- This means tapping heat from fracture zones and active volcanoes undersea.

d. Fresh Water

- Several desalination technologies are in operation, but as yet they are not being used on a large scale, as they are costly.

Technologies adopted in desalinization of sea water

- **Electrodialysis** employs iron-selective membranes for the desalination of brackish water.
- **Flash distillation** 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.

e. Biotic Resources

- At the base of the food chain are the planktons—phytoplankton and zoo-planktons. These are the food for many marine animal species.
- Benthos (sea surface) resources include animals such as crustaceans (prawn, shrimp, crab, lobster) and shellfish or molluscs (mussels, oysters).
- Marine animals provide oil, fur, leather, glue and cattle feed.
- Marine plants and animals are used in curative medicine.
- Seafoods are of high nutritional value.
- Edible fish are of three main types, based on the location of habitat.
    1. Pelagic fish (mackerel, herring, anchovies, tuna) breed near the surface of seas.
    2. 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.
    3. Then there are the migratory anadromous fish (salmon) that live in the sea but move into fresh water of coastal rivers every year.
- Whales are mammals of the ocean and have been caught not only for food but for industrial and medicinal purposes as well.

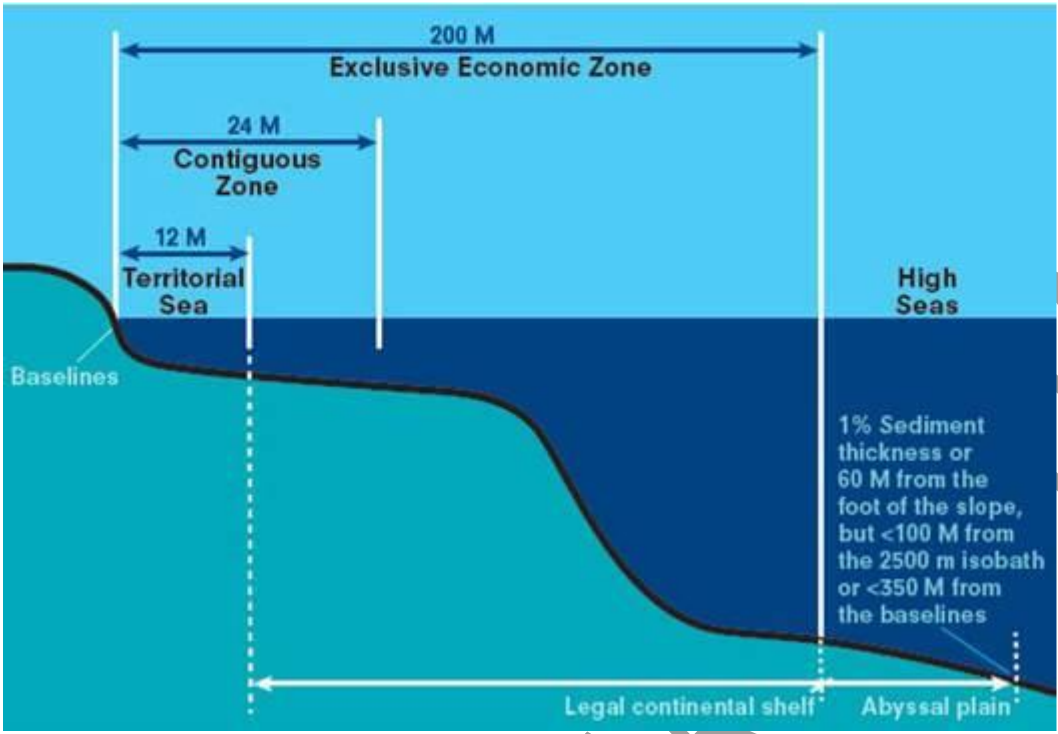
i. Algae

- Algae such as sea lettuces are used in soups and salads and as flavouring.

- Kelp can be cultivated for producing methane gas and used as an energy source by bioconversion
- Brown algae produce algin.
- 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, and in cosmetics and medicines.

f. United Nations International Conferences on the Law of the Sea (UNCLOS)

- UNCLOS is an **international agreement** that defines the **rights and responsibilities of nations** where **use of the oceans' waters** by them is concerned.
- UNCLOS deal with aspects like delimitation, control of environmental pollution, commercial activities in the seas, technology transfer and settlement of disputes between States with reference to ocean matters.
- It also creates a legal regime for controlling mineral resource exploitation in deep seabed areas beyond national jurisdiction, through an International Seabed Authority.
- The UNCLOS came into force in the year 1994.
- As of today, it has been signed by more than 150 countries.
- The **USA has signed the treaty but has not ratified it**.
- The UN provides support for Convention meetings. However, the UN does not have a direct part in the implementation of the Convention.
- But organizations like the **International Maritime Organisation** and the **International Whaling Commission** have a role to play.
- UNCLOS uses a **consensus** process rather than a majority vote to discourage groups of nation-states dominating negotiations.
- Four main decisions have been widely accepted since 1978.



UNCLOS Coastal Zones

i. Territorial waters

- Territorial waters are those waters over which a state has full sovereignty
- Territorial waters extend for 19 km (**12 miles**) from the coast.
- Territorial waters include fjords, estuaries and land between the mainland and offshore islands in the internal waters.

ii. Contiguous Zone or Pursuit Zone

- A further contiguous zone of 19 km is recognized in which the coastal state can act against those who break the law (smugglers, pirates, illegal immigrants etc.) within the true territorial waters.
- This, in other words, is a **pursuit zone**.

iii. Exclusive Economic Zone (EEZ)

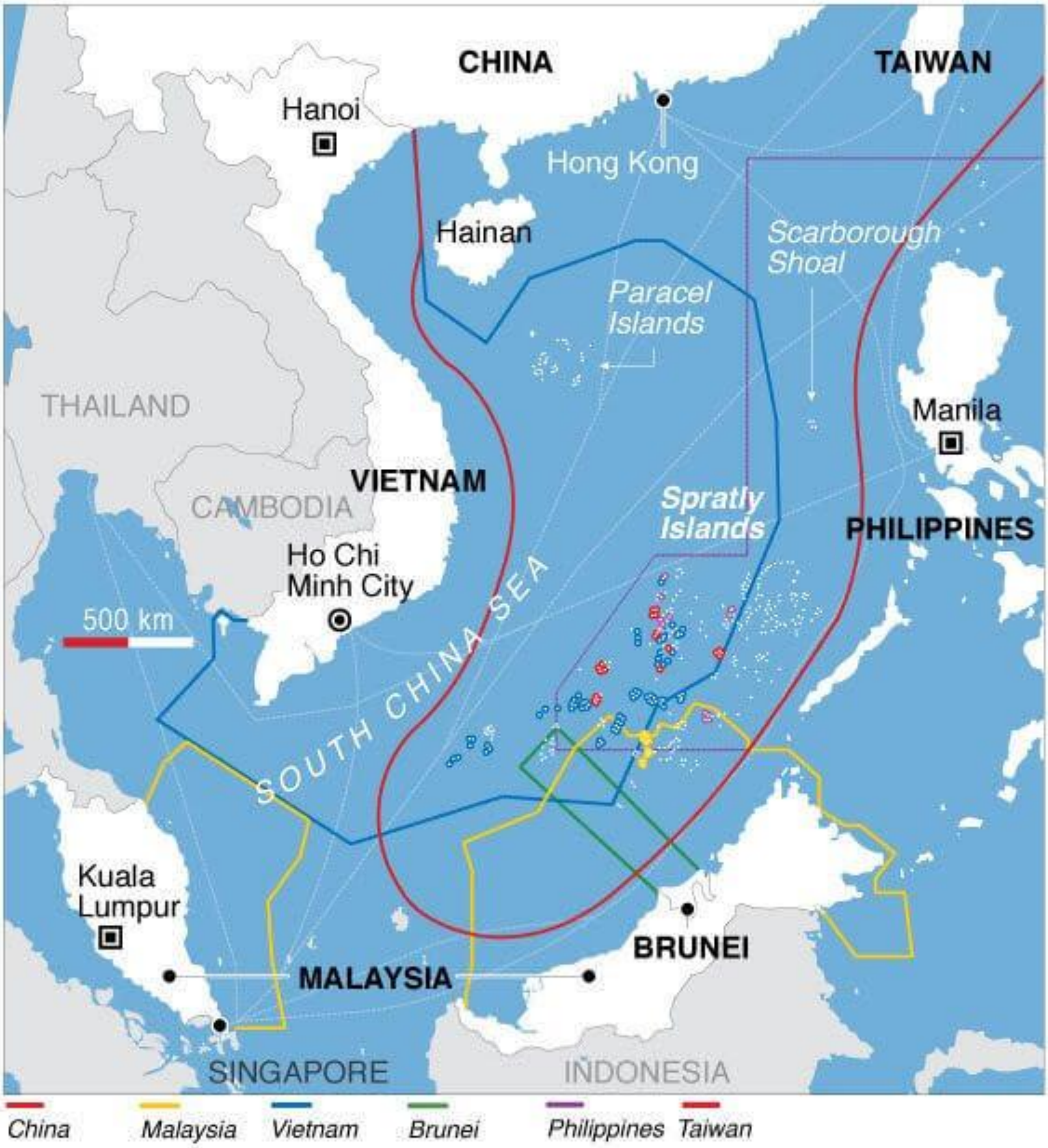
- Exclusive economic zone (EEZ) starts at the same baseline as the territorial waters.
- EEZ extend for 320-km (**200-mile**) from the baseline.
- Within the EEZ the coastal state has the right to **exploit all economic resources** — fish, minerals, oil and gas and energy production.

- 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.
- 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.
- 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.

iv. High Seas

- 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.
- The States must share with the international community part of the revenue derived from exploiting resources on the continental shelf extending beyond 200 miles.
- Special protection should be accorded to highly migratory species of fish and sea mammals.

v. Land Disputes in South China Sea: Parcel Islands and Spratly Islands

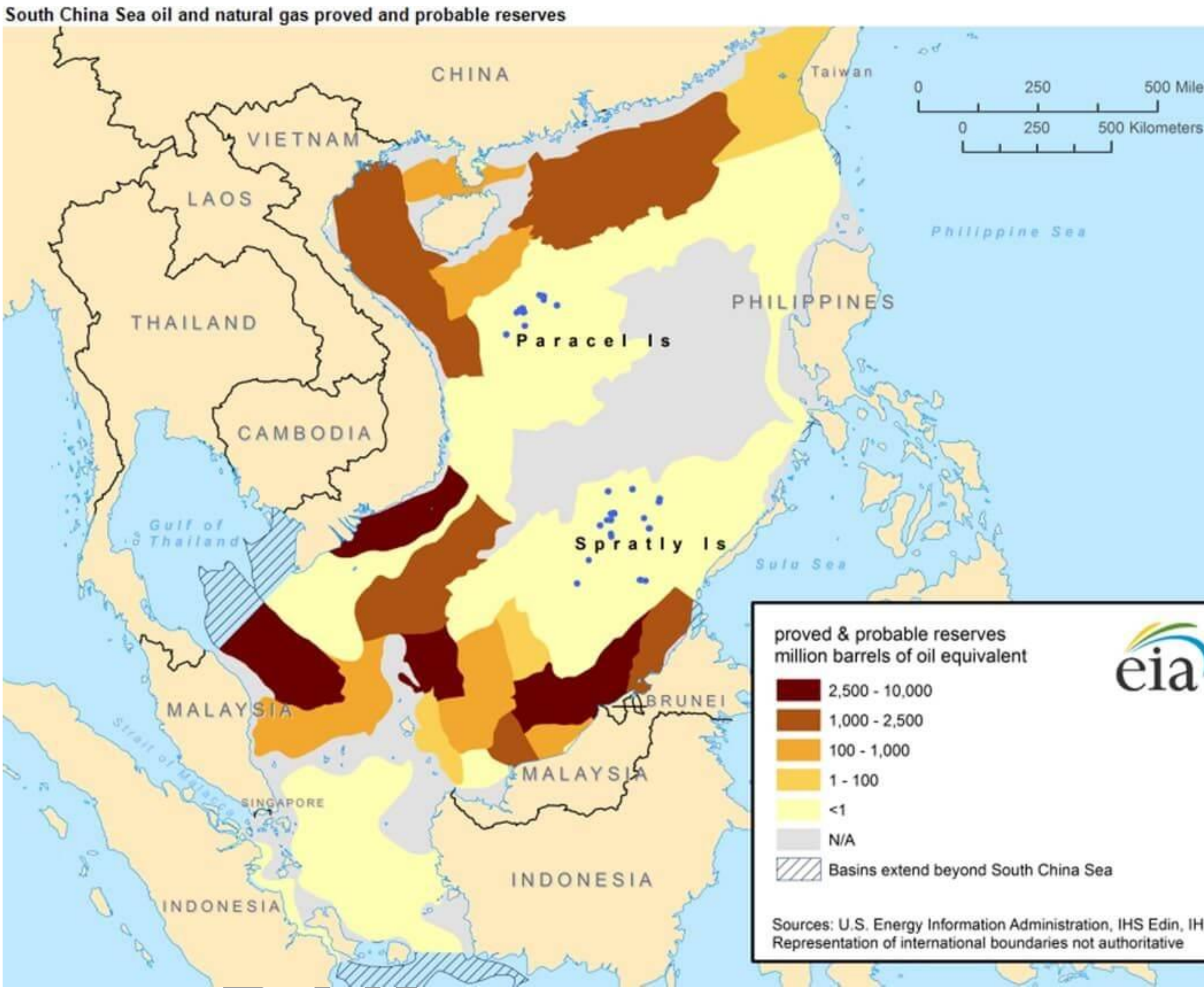


Parcel Islands and Spratly Islands in South China Sea (Voice of America, Wikipedia)

- The **Spratly Islands and Paracel Islands** are two of the most contested areas in the South China Sea.
- However, unlike other parts of the South China Sea, these areas do not hold large resources of oil and natural gas.
- Most fields containing discovered oil and natural gas are clustered in uncontested parts of the South China Sea, close to shorelines of the coastal countries.
- The Paracel Islands, however, contain significant natural gas hydrate resources.
- Under the UNCLOS, ownership of habitable islands can, however, extend the exclusive access of a country to surrounding energy resources (**200 mile EEZ**).

- Hence, the country that wins the dispute would have the right to explore and develop whatever the resources that are available in the EEZ.

Competing Claims in the South China Sea



Oil and Gas reserves around Spratly Islands and Parcel Islands (Source)

1. Economic and Strategic importance of South China Sea

- 10% of world's fisheries.
- 30% of global shipping trade.
- Population is 2.2 billion in the region.
- 11 billion barrels of oil.
- 190 trillion cubic feet of natural gas.

Source

https://www.geographyandyou.com/pelagic-deposits-red-clay-oozes-ocean/