VISION IAS

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GEOGRAPHY PART 1

Student Notes:

THE UNIVERSE AND SOLAR SYSTEM

Contents

1. The Universe

The vast space surrounding us is called universe. It is mostly empty space. The universe includes everything that exists: the most distant stars, planets, satellites, as well as our own earth and all the objects on it. Nobody knows how big the universe is or whether it has any limits. However, it is estimated that the Universe contains 100 billion galaxies, each of which comprises 100 billion stars. The sun which sustains all the life on our planet is only one of the billions and billions of stars that exist in this universe, whereas the planet earth on which we live is only a tiny speck in this vast space called universe. The earth is one of the **eight planets**, all of which revolve around a central star called sun. The billions stars which exists in the universe are not distributed uniformly in space. These stars occur in the form of clusters (or groups) of billions of stars called galaxies. Thus, in order to study the constitution of this universe we have to first discuss the objects like galaxies, stars, planets and satellites, etc., which are found in the universe.

2. Origin of the Universe

The most popular argument regarding the origin of the universe is the **Big Bang Theory**. It is also called **expanding universe hypothesis**. Edwin Hubble, in 1920, provided evidence that the universe is expanding. As time passes, galaxies move further and further apart. The distance between the galaxies is found to be increasing and thereby, the universe is considered to be expanding. Here, the expansion of universe means increase in space between the galaxies. However, Scientists believe that though the **space between the galaxies** is increasing, observations do not support the expansion of galaxies in itself.

An alternative to this was **Hoyle's concept of steady state. It considered the universe to be roughly the same at any point of time. It did not have a beginning and did not have an end.**

However, with greater evidence becoming available about the expanding universe, scientific community at present favours argument of expanding universe.

Stages in Big Bang Theory

(i) In the beginning, all matter forming the universe existed in one place in the form of a "tiny ball" (singular atom) with an unimaginably small volume, infinite temperature and infinite density.

(ii) At the Big Bang the "tiny ball" exploded violently. This led to a huge expansion. It is now generally accepted that the event of big bang took place 13.7 billion years before the present. The expansion continues even to the present day. As it grew, some energy was converted into matter. There was particularly rapid expansion within fractions of a second after the bang. Thereafter, the expansion has slowed down. Within first three minutes from the Big Bang event, the first atom began to form.

(iii) Within 300,000 years from the Big Bang, temperature dropped to 4,500 K and gave rise to atomic matter. The universe became transparent.

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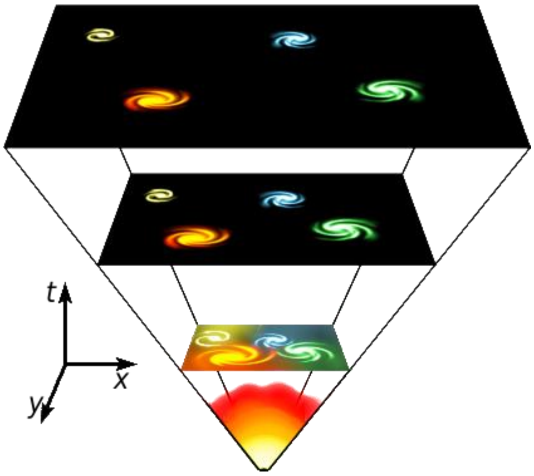


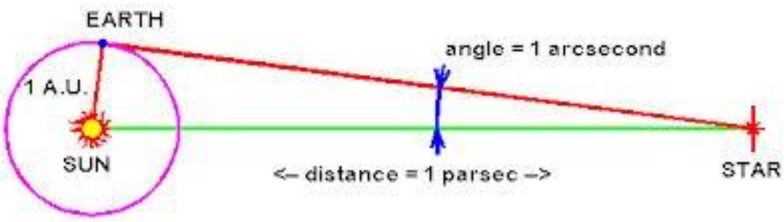
Evidences in Support of Big Bang Theory

Evidence	Interpretation
The light from other galaxies is red-shifted.	The other galaxies are moving away from us.
The further away the galaxy, the more its light is red-shifted.	The most likely explanation is that the whole universe is expanding. This supports the theory that the start of the universe could have been from a single explosion.
Cosmic Microwave Background	The relatively uniform background radiation is the remains of energy created just after the Big Bang.

According to ***Nebular Hypothesis*** the planets were formed out of a cloud of material associated with a youthful sun, which was slowly rotating. The theory was give by German Philosopher Immanuel Kant (Though he did not use word Nebular) and later revised by Mathematician Laplace in 1796. You will learn about Kant in Moral Thinkers (GS Paper IV).

2.1. The Units of Measuring Distances in the Universe

- The extremely vast distances between the various heavenly bodies like the stars and planets can be well expressed in terms **Astronomical Unit (A.U), Light year, and Parsec.**
- **Astronomical unit** is defined as the mean distance from the earth to the sun. One AU is equal to 1.5×10^8kilometres.
- **Light year** is the distance travelled by light in one year. It is equal to 9.46×10^{12} kilometres.
- **Parsec:** It represents the distance at which the radius of Earth's orbit subtends an angle of one second of arc. One parsec equals about 3.26 light-years or 30.9 trillion kilometres.



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3. Galaxy

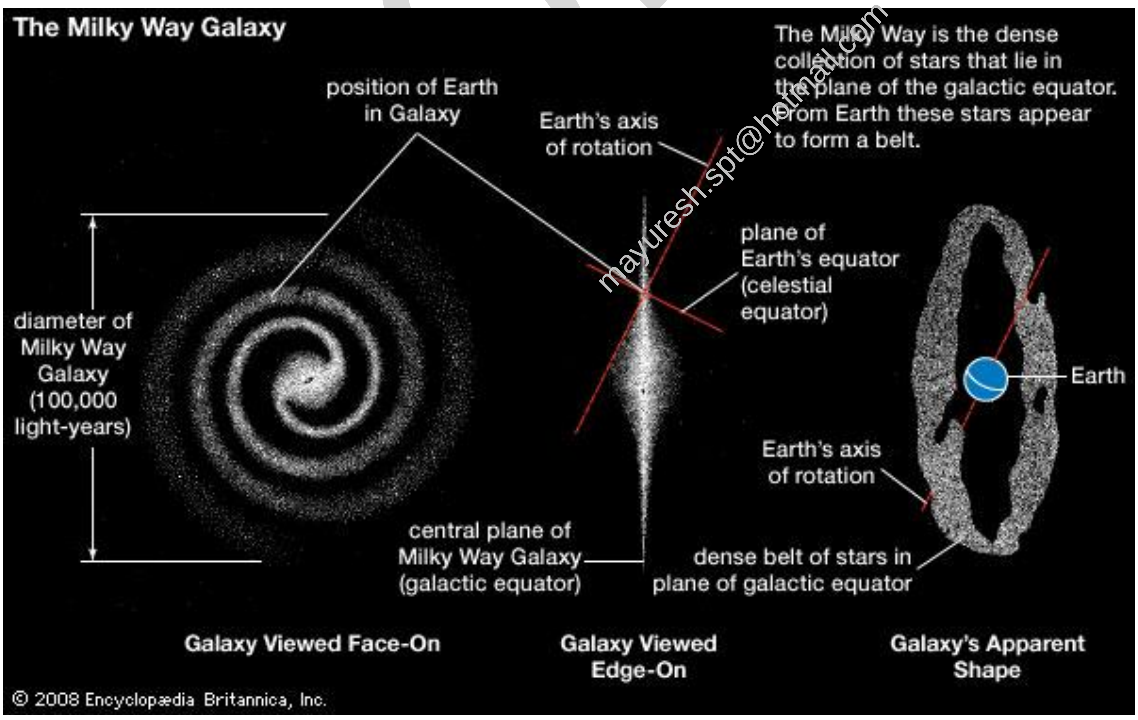
Galaxies are building blocks of the universe. Galaxy is a vast system of billions of stars, which also contains a large number of gas clouds mainly of hydrogen gas (where stars are born), and dust, isolated in space from similar system.
Classification of galaxies
Galaxies are usually classified on the basis of their shape and are of three types :

1) Spiral
2) Elliptical
3) Irregular

Some of the brightest galaxies are elliptical galaxies but spiral galaxies are usually much bigger than others. We live on the outer edge of a spiral type of galaxy called milky way.

3.1. Our Own Galaxy: The Milky Way

- It is a spiral type of galaxy.
- It is about 100000 light years in diameter and has disk-shaped structure.
- The Milky Way galaxy is rotating slowly about its centre in the counter-clockwise direction.
- All the stars (The sun too along with the solar system) rotate about the centre of the Milky Way galaxy.
- The disc of stars is quite thick at the centre representing a relatively high concentration of the stars at the centre of the galaxy.
- The sun is far away(~27000 LY) from the centre of the Milky Way galaxy.
- Since the Milky Way galaxy appears like a river of light in the night sky running from one corner of the sky to the other, it is called ‘Akash Ganga’.



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4. Stars

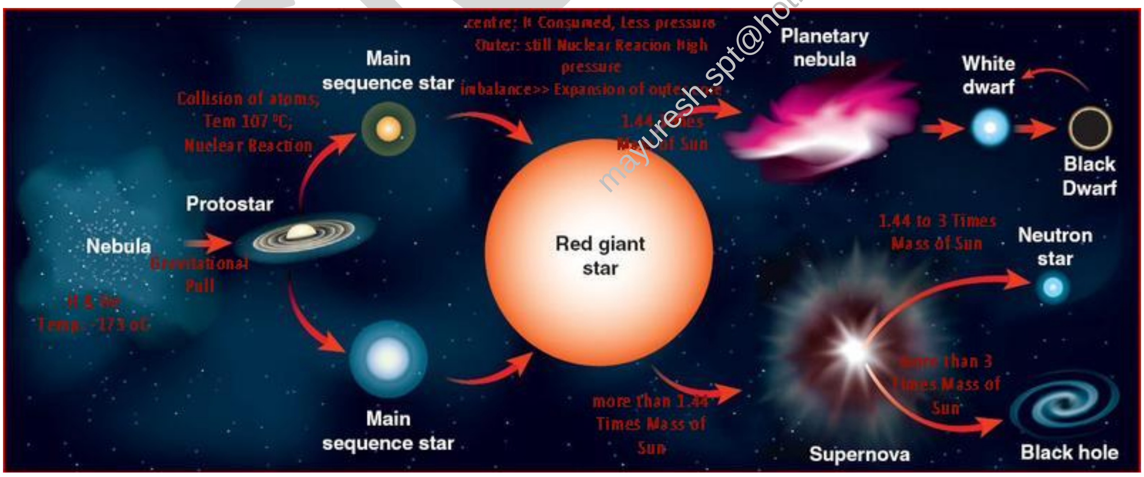
Stars are the heavenly bodies like the sun that are extremely hot and have light of their own. **Stars are made up of vast clouds of hydrogen gas, some helium and dust.** In all the stars (including the sun), hydrogen atoms are continuously being converted into helium atoms and a large amount of nuclear energy in the form of heat and light is released during this process. It is this heat and light which makes a star shine. Thus, **a star is a hydrogen nuclear energy furnace, so big that it holds together by itself**. The stars are classified according to their physical characteristics like size, colour, brightness and temperature.

Stars are of three colours: red, white and blue. The colour of a star is determined by its surface temperature. The stars which have comparatively **low surface temperature are red**, the star having **high surface temperature are white** whereas those stars which have **very high surface temperature are blue** on colour. **Some of the important example** of the stars are: Pole (or Polaris), Sirius, Vega, Capella, Alpha centauri, Beta centauri, Proxima centauri, Spica, Regulus, Pleiades, Aldebaram, Arcturus, Betelgeuse, and of course, the Sun.

All the stars (except the pole star) appear to move from east to west in the night sky. This can be explained as follows: the earth itself rotates on its axis from west to east. So, when the earth rotates on its axis from west to east, the stars appear to move in the opposite direction, from east to west. Thus, the apparent **motion of the stars in the sky is due to the rotation of the earth on its axis**. Since we are ourselves on the earth, the earth appears to be stationary to us but the stars appear to be moving in the sky. Thus, it is due to the rotation of earth on its axis that we see the stars changing their positions in the sky as the night progresses.

4.1. Birth and Evolution of a Star

The raw material for the formation of a star is mainly hydrogen gas and some helium gas. The life cycle of a star begins with the gathering of hydrogen gas and helium gas present in the galaxies to form dense clouds of these gases. The stars are then formed by the gravitational collapse of these over-dense clouds of gases in the galaxy. Let us deal the various stages in the formation of star-



4.1.1. Formation of a Protostar

In the beginning, the gases in the galaxies were **mainly hydrogen with some helium**. However, they were at a **very low temperature of about, -173°C.** Since the gases were very cold, they formed **very dense clouds** in the galaxies. In addition, the gas cloud was very large, so the **gravitational pull** between the various gas molecules was quite large. Due to large gravitational force, the gas cloud started contracting as a whole. Ultimately, the gas were compressed so much that they formed a highly condensed object called a protostar. A protostar looks a like a huge, dark, ball of gas. The formation of protostar is only a stage in the formation of complete star. A **protostar does not emit light**. The next stage consists in the transformation of this highly condensed object called protostar into a star which emits light.

4.1.2. Formation of a Star from Protostar

The protostar is a **highly dense gaseous mass**, which continues to **contract further due to tremendous gravitational force.** As the protostar begins to contract further, the **hydrogen atoms present in gas cloud collide with one another** more frequently. These **collisions of hydrogen atoms raise the temperature of protostar more and more**. The **process of contraction** of protostar **continues for about a million years** during which the inner temperature in the protostar increases from a mere, -173°C in the beginning to about 10^7°C. At this extremely high temperature, nuclear fusion reactions of hydrogen start taking place. In this process, four small hydrogen nuclei fuse to produce a bigger helium nucleus and a tremendous amount of energy is produced in the form of heat and light. The energy produced during the fusion of hydrogen to form helium makes the protostar glow and it becomes a star. This star shines steadily for a very, very long time.

4.1.3. Final Stages of a Star's Life

In the first part of the final stage of its life, a star enters the **red-giant phase** where it becomes a red-giant star. After that, **depending on its mass**, the red-giant star can die out by becoming a **white dwarf star**, or by exploding as a **supernova star**, which ultimately ends in the formation of **neutron star** and **black holes**.

(1) Red- Giant Phase. Initially, the stars contain mainly hydrogen. With the passage of time, hydrogen gets converted into helium from the centre outwards. Now, when all the hydrogen present in the core of the star gets converted into helium, then the fusion reactions in the core would stop. Therefore, ultimately, the matter in the core of the star would consist only of helium. Due to the stoppage of fusion reactions, the pressure inside the core of the star would diminish, and the **core would begin to shrink** under its own gravity. In the outer shell or envelope of the star, however, some hydrogen still remains, the fusion reactions would continue to liberate energy but with much reduced intensity. Due to all these changes, the **overall equilibrium in the star is upset** and **in order to readjust it, the star has to expand considerably** in its exterior region(outer region). Thus the star becomes very big (it becomes a giant), and its colour changes to red. At this stage, the star enters the red-giant phase and it is said to become a red-giant star. Our own star, the sun, will ultimately turn into a red-giant star after about 5000 million year from now. The expanding outer shell of the sun will then become so big that it will engulf the inner planets like mercury and Venus, and even the earth.
When a star reaches the red-giant phase, then its future depends on its initial mass. Two cases arise:

(a) If the initial mass of the star is comparable to that of the sun, then the red-giant star loses its expanding outer shell and its core shrinks to form a white dwarf star which ultimately dies out as a dense lump of matter into the space.

(b) If the initial mass of the star is much more than of the sun, then the red-giant star formed from its explodes in the form of a supernova star, and the core of this exploding supernova star can shrink to form a neutron star or black hole.

(2) Formation of White Dwarf Star: If the mass of red-giant star is similar to that of the sun, the red-giant star would lose its expanding outer shell or envelope because then the comparatively smaller amount of hydrogen fuel present in it will be used up rapidly, and only the core of the red-giant star will gradually shrink into an extremely dense ball of matter due to gravitation. Because of this enormous shrinking of helium core, the temperature of core would rise greatly and start another set of nuclear fusion reactions in which helium is converted into heavier elements like carbon, and an extremely large amount of energy will be released. When the mass of a star is similar to the mass of the sun (which is comparatively a small mass), then all the helium is converted into carbon in a short time and then further fusion reactions stop completely. Now, as the energy being produced inside the star stops, the core of star contracts (shrinks) under its own weight. And it becomes a white dwarf star.

A great Indian scientist Chandrasekhar made a detailed study of the stars which end their lives by becoming white dwarf stars. Chandrasekhar concluded that the start having a mass less than 1.44 times the solar mass (or sun's mass) would end up as white dwarf stars. The maximum limit of 1.44 times the solar mass (for a star to end its life as a white dwarf) is known as 'Chandrasekhar Limit'. If, however, a star has a mass more than 1.44 times the solar mass or sun's mass, then it will not die out by becoming a white dwarf star. This is because due to greater mass, it will have more nuclear fuel in it, which will not get exhausted in a short time. The stars having mass much more than solar mass (or sun's mass) led to supernova explosions and end their lives by becoming neutron stars or black holes. This point will become clearer from the following discussion:

4.1.4. Formation of Supernova Star and Neutron Star

When a very big star is in the red-giant phase, then being big, its core contains much more helium. This big core made up of helium continues to contract (shrink) under the action of gravity producing higher and higher temperature. At this extremely high temperature, fusion of helium into carbon takes place in the core and lot of energy is produced. Since the star was very big and contained enormous nuclear fuel helium, so a tremendous amount of nuclear energy is produced very rapidly which causes the outer shell (or envelope) of this red-giant star to explode with a brilliant flash like a nuclear bomb. This type of 'exploding star is called supernova. The energy released in one second of a supernova explosion is equal to the energy released by the sun in about 100 years. This tremendous energy would light up the sky for many days. When a supernova explosion takes place, then clouds of gases in the envelope of red-giant star are liberated into the space and these gases act as raw material for the formation of new stars. The heavy core left behind after the supernova explosion continues to contract and ultimately becomes a **neutron star** (if mass of star was 1.44 time to 3 times the Sun) or **Black Hole** (if the mass of star was more than 3 times the sun).

A neutron star contains matter in even denser form than found in white dwarf stars. Although a number of white dwarfs have been detected, but no one has yet observed a neutron star. This may be because neutron stars are very faint. A spinning neutron star emits radio waves and is called a **pulsar**.

5. Black Holes

A black hole is an object with such a strong gravitational field that even light cannot escape from its surface. A black hole may be formed when a massive object (very big object) undergoes uncontrolled contraction (a collapse) because of the inward pull of its own gravity. We will now describe how the black holes are formed from neutron stars after the supernova explosions of big stars. **When a supernova explosion of a very massive star takes place, then the gaseous matter present in the outer shell(or envelope) of the star is scattered into space but the core of the star survives during supernova explosion.** This heavy core of the supernova star continues to contract (shrink) and becomes a neutron star. The fate of this neutron star depends on its mass. If the neutron star is very heavy, then due to enormous gravitational attraction, it would continue to contract indefinitely. And the vast amount of matter present in a neutron star would be ultimately packed into a mere point object. Such an infinitely dense object is called a black hole. **Thus black holes are formed by the indefinite contraction of heavy neutron stars under the action of their own gravity**. The neutron stars shrink so much and become so dense that the resulting black holes do not allow anything to escape, not even light, from their surface. This is because the black holes have tremendous gravitational force. Since even light cannot escape from blackholes, therefore, **black holes are invisible, they cannot be seen. The presence of a black hole can be felt only by the effect of its gravitational field on its neighbouring objects in the sky.** For example, if we see a star moving in a circle with no other visible stars in the centre, then we can conclude that there is a black hole at the centre. And it is the gravitational pull exerted by this black hole which is making the star goes in a circle around it.

Dark matter[1]

Dark matter is a type of matter hypothesized in astronomy and cosmology to account for a large part of the mass that appears to be missing from the universe. Dark matter cannot be seen directly with telescopes; evidently it neither emits nor absorbs light or other electromagnetic radiation at any significant level. Dark Matter is not exactly balck hole. The composition of the constituents of cold dark matter is currently unknown. It could be group of black holes, dwarfs or some new particle.

6. The Solar System

The solar system consists of the sun, the eight planets and their satellites, and thousands of other smaller heavenly bodies such as asteroids, comets and meteors. The Solar System is at a distance of about 27,000 light years from the centre of the Milky Way galaxy and is about 5 billion years old. The sun is at the centre of the solar system and all these bodies are revolving around it. The gravitational pull of the sun keeps all the solar system and all the planets and other objects revolving round it. Thus, the motion of all members of the solar system is governed mainly by the gravitational force of the sun.

The solar system is dominated by the sun. The sun accounts for almost 99.9 percent of the matter in the whole solar system. The sun is also the source of all the energy in the solar system.

6.1. Sun

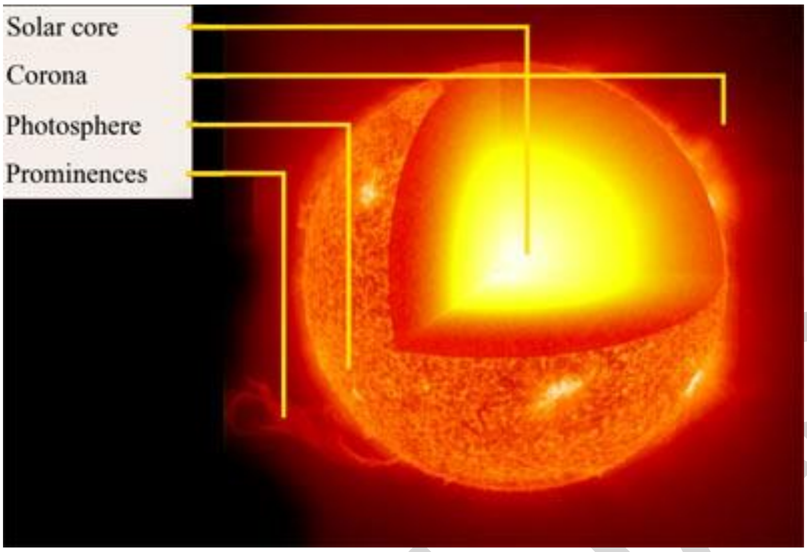
The sun is the head of solar family or solar system. Compared with the millions of other stars, the sun is a medium sized star and of average brightness... Though sun is the nearest star to the earth, even then it is at a distance of 150×10^6kilometres from the earth and light, travelling at a great speed of 300,000 kilometres per second, takes about 8 minutes and 20 seconds to reach us from the sun. However, light takes about 4.3 years to reach us from the next nearest star called **proxima centauri**.

Sun is not a solid body. The sun is a sphere of hot gases. It consists mostly of hydrogen gas.. The nuclear fusion reactions taking place in the centre of the sun(in which hydrogen is converted into helium) produce a tremendous amount of energy in the form of heat and light. It is this energy, which makes the sun shine From the Earth, we see only the surface of the sun. The shining surface of the sun is called photosphere. The surface of the sun (photosphere) appears

[1] Details of dark matter and dark energy will be discussed in Science and Technology notes.

Student Notes:

like a bright disc to us, it is also known as disc of the sun. It is this bright, shining disc of the sun (or photosphere) which radiates energy and acts as a source of energy for us. The temperature at the sun (or the temperature of the bright disc of the sun) is about 6000°C. The temperature at the centre of the sun is about 15 million °C. The outer layer of the sun's atmosphere made up of thin, hot gases is called corona. The corona is visible only during a total eclipse of the sun.



6.2. Planets

Planets are solid heavenly bodies which revolve round a star (e.g. the sun) in closed elliptical paths. A planet is made of rock and metal. It has no light of its own. A planet shines because it reflects the light of the sun. since the planets are much nearer than the stars, they appear to be big and do not twinkle at night. The planets move round the sun from west to east, so the relative positions of the planets keep changing day by day. The planets are very small as compared to the sun or other stars. There are 8 major planets including the earth. These planets in the order of increasing distances from the sun are given below-

1. Mercury (Budha): it is nearest to the sun.
2. Venus (Shukra)
3. Earth (Prithvi)
4. Mars (Mangal)
5. Jupiter (Brihaspati): Biggest Planet.
6. Saturn (Shani)
7. Uranus (Arun)
8. Neptune (Varun)

IAU new definition of planet

The definition of **planet** set in 2006 by the International Astronomical Union (IAU) states that, in the Solar System, a planet is a celestial body which:

- is in orbit around the Sun,
- has sufficient mass to assume hydrostatic equilibrium (a nearly round shape), and
- Has "cleared the neighbourhood" around its orbit. For this they become the dominant gravitational body in their orbit in the Solar System. Pluto lacks it.

Any object if meet the first two criteria but doesn't meet the 3rd criteria is considered a **dwarf planet**. Thus Pluto is a dwarf planet.

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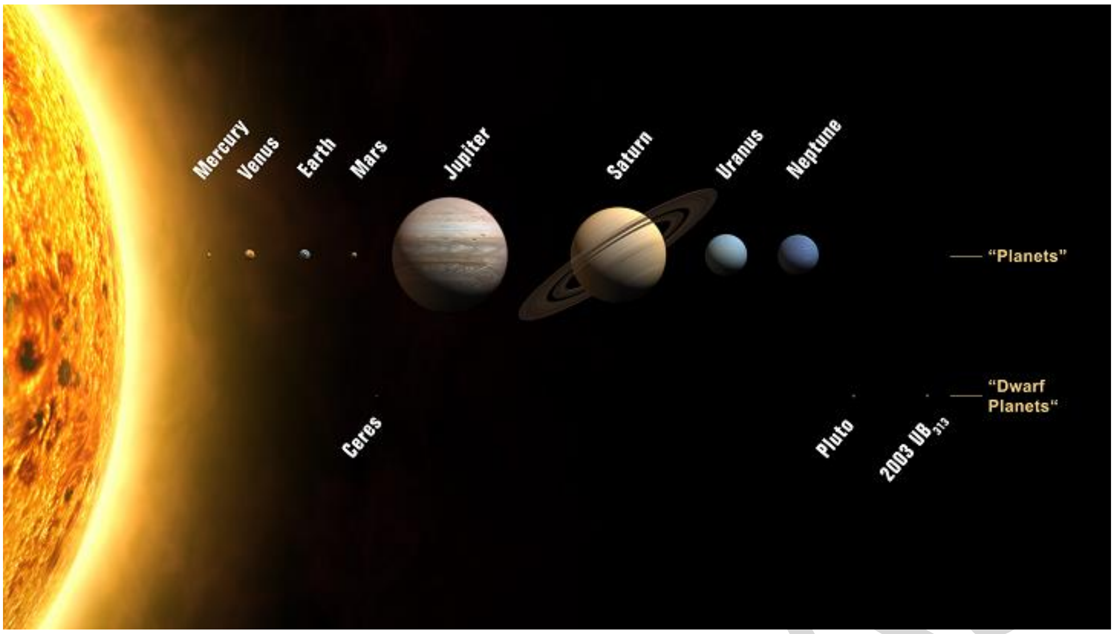

Planets and dwarf planets of our solar system (Milky Way)

The 8 planets have been divided into two groups. All the planets of a particular group have some common features. The two groups of planets are:

1. Terrestrial Planets
2. Jovian Planets

The four nearest planets to the Sun, **Mercury, Venus, Earth and Mars**, are called terrestrial planets, because their structure is similar to earth.

The common features of the **terrestrial planet**s are:

1. They have a thin, rocky crust.
2. They have a mantle rich in iron and magnesium.
3. They have a core of heavy metals.
4. They have thin atmosphere.
5. They have very few natural satellites (or moons) or no satellites.

They have varied terrain such as volcanoes, canyons, mountains, and craters. The planets which are outside the orbit of Mars are called **Jovian planets** because their structure is similar to that of Jupiter. The Jovian planets are: Jupiter, Saturn, Uranus, and Neptune.

The common features of the Jovian planets are:

1. They are all gaseous bodies (made of gases)
2. They have ring system around them.
3. They have a large number of natural satellites (or moons).

Solar System Fact Sheet

(For reference only. Do not try to memorise facts.)

	Sun	MERCURY	VENUS	EARTH	MOON	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Mass (10^{24}k)	1,988,500	0.33	4.87	5.97	0.073	0.642	1898	568	86.8	102	0.0131
Diameter (km)	1,392,684	4879	12,104	12,756	3475	6792	142,984	120,536	51,118	49,528	2390

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Density (kg/m3)	1,408	5427	5243	5514	3340	3933	1326	687	1271	1638	1830
Gravity (m/s2)		3.7	8.9	9.8	1.6	3.7	23.1	9	8.7	11	0.6
Escape Velocity (km/s)		4.3	10.4	11.2	2.4	5	59.5	35.5	21.3	23.5	1.1
Rotation Period (hours)		1407.6	-5832.5	23.9	655.7	24.6	9.9	10.7	-17.2	16.1	-153.3
Length of Day (hours)		4222.6	2802	24	708.7	24.7	9.9	10.7	17.2	16.1	153.3
Distance from Sun (106 km)		57.9	108.2	149.6	0.384	227.9	778.6	1433.5	2872.5	4495.1	5870
Perihelion (106 km)		46	107.5	147.1	0.363	206.6	740.5	1352.6	2741.3	4444.5	4435
Aphelion (106 km)		69.8	108.9	152.1	0.406	249.2	816.6	1514.5	3003.6	4545.7	7304.3
Orbital Period (days)		88	224.7	365.2	27.3	687	4331	10,747	30,589	59,800	90,588
Orbital Velocity (km/s)		47.9	35	29.8	1	24.1	13.1	9.7	6.8	5.4	4.7
Orbital Inclination (degrees)		7	3.4	0	5.1	1.9	1.3	2.5	0.8	1.8	17.2
Orbital Eccentricity		0.205	0.007	0.017	0.055	0.094	0.049	0.057	0.046	0.011	0.244
Axial Tilt (degrees)		0.01	177.4	23.4	6.7	25.2	3.1	26.7	97.8	28.3	122.5
Mean Temperature (C)		167	464	15	-20	-65	-110	-140	-195	-200	-225
Surface Pressure (bars)		0	92	1	0	0.01	Unknown	Unknown	Unknown	Unknown	0
Number of Moons		0	0	1	0	2	67	62	27	14	5
Ring System?		No	No	No	No	No	Yes	Yes	Yes	Yes	No
Global Magnetic Field?		Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Unknown

(Source: http://nssdc.gsfc.nasa.gov/planetary/factsheet/)

6.3. Satellites (or Moons)

A satellite (or moon) is a solid heavenly body that revolves round a planet. The moon revolves round the earth, so moon is a satellite of the earth.. Except Mercury and Venus all other planets of solar system have satellites. The satellites have no light of their own. They shine because they reflect the light of the sun. It should be noted that though we commonly call earth's natural satellite as moon, the satellites of all other planets can also be called their moons.

Earth's moon key points:

- The moon is a natural satellite of the earth.
- Moon revolves round the earth on a definite, regular path- the moon's orbit.
- Gravitational attraction of the earth holds the moon in its orbits.
- The moon is about one-fourth the size of the earth in diameter and weight is about one-eighth that of the earth.
- Moon has no air or water. Its surface is covered with hard and loose dirt, craters and mountains.
- On the moon, days are extremely hot and nights are very cold.
- Because the moon is nearer to the earth, it appears to be much bigger than the stars.
- The moon has no light of its own, it is light from the sun which is reflected by the moon's surface.

Origin of Moon

In 1838, Sir George Darwin suggested that initially, the earth and the moon formed a single rapidly rotating body. The whole mass became a dumb-bell-shaped body and eventually it broke. It was also suggested that the material forming the moon was separated from what we have at present the depression occupied by the Pacific Ocean.

However, the present scientists do not accept either of the explanations. It is now generally believed that the formation of moon, as a satellite of the earth, is an outcome of 'giant impact' or what is described as "the big splat". A body of the size of one to three times that of mars collided into the earth sometime shortly after the earth was formed. It blasted a large part of the earth into space. This portion of blasted material then continued to orbit the earth and eventually formed into the present moon about 4.44 billion years ago.

Other Objects in the sky: In addition to the stars, planets and satellite, there are three other objects which we can occasionally see in the sky during night. These are asteroids, comets and meteors. We will discuss all of them one by one.

6.4. Asteroids

Asteroids are very small planets of rock and metal which revolve round the sun mainly between the orbits of mars and Jupiter. Actually, asteroids are a belt of a kind of debris, which somehow failed to assemble into a planet and keep revolving between the orbits of mars and Jupiter. There may be as many as 100,000 asteroids. The biggest asteroid called 'ceres' has a diameter of about 800 kilometres whereas the smallest asteroid is as small as pebble. Some experts believe that asteroids are the pieces of a planet that went close to Jupiter and was broken up by its gravitational pull. Others think that they are part of a ring of separate pieces of matter formed at the same time as the planets.

Sometimes an asteroid can collide with earth. Though the collision of an asteroid with the earth happens very rarely, even then a careful watch is kept on the motion of asteroids by the astronomers. This is because the collision of an asteroid with the earth can cause a lot of damage to life and property on the earth. In fact, the extinction of dinosaurs the earth which occurred about 65 million years ago, is believed to have been caused by the collisions of some asteroids with the earth.

When an asteroid collides with the earth, then a huge crater is formed on the surface of the earth. Many such collisions of the asteroids must have occurred in the past during the entire history of the earth which may have caused craters of different sizes on its surface. However, the natural process of soil erosion like wind and rain, tend to fill up these craters in due course of time. Only a few such craters survived on the surface of the earth so far. The 'Lonar Lake' in Maharashtra is one such crater formed by the collision of an asteroid with the earth.

Student Notes:

6.5. Comets

According to new definition, Neptune is the outermost planet of the solar system. However, it's orbit does not mark the boundary of the solar system. The solar system extends much beyond at the edge of the solar system, there are billions of very small objects called 'comets' these comets were formed very early from the same gas cloud from which other members of the collar system were made. These comets are so far off that normally they cannot be seen. They keep on revolving around the Sun, unknown to the world.

Sometimes, however, the normal path of a comet is disturbed and the comet starts moving towards the sun. As the comet approaches the sun, it develops a long, glowing tail and becomes visible only when it approaches the sun because the sun's rays make its gas glow which spreads out to form a tail millions of kilometres long. And it presents a spectacular sight. Thus, a comet is a collection of gas and dust, which appears as a bright ball of light in the sky with a long glowing tail. The **tail of a comet always points away from the sun**. Comets revolve around the sun like planets. The period of revolution of comets around the sun is, however, very large. For example, Halley's Comet has a period of about 76 years. Halley's Comet last appeared in the inner Solar System in 1986 and will next appear in mid-2061.

Just like asteroids, comets are also of great interest to scientists. This is because they are made of the same material from which the whole solar system was made. The study of the tail of the comets has shown the existence of molecules of carbon, oxygen, hydrogen and nitrogen such as CO, CH_4 and HCN on it. Since these simple molecules help to form complex molecules necessary for the origin of life, some scientist have suggested that the seeds of life on the earth were brought by comets from the outer space. Comets do not last forever. Each time a comet passes the sun, it loses some of its gas and ultimately only the dust particles are left in space. When these particle enter into the earth's atmosphere, they burn up due to heat produced by air resistance and produce a shower of meteors or **shooting stars**.

6.6. Meteors

Many times we see a streak of light in the sky during night which disappears within seconds. It is called a meteor or shooting star. Meteors are the heavenly bodies from the sky which we see as a bright streak of light that flashes for a moment across the sky. The meteors are also called shooting stars. Some meteors are the dust particles left behind by comets and others are the pieces of asteroid which have collided. When a meteor enters into the atmosphere of earth with high speed, a lot of heat is produced due to the resistance of air. This heat burns the meteor and the burning meteor is seen in the form of a streak of light shooting down the sky, and it falls on the earth in the form of dust.

If a meteor is big, a part of it may reach the earth's surface without being burned up in air. This fragment is called a **meteorite**. Thus, **a meteor which does not burn completely on entering the earth's atmosphere and lands on earth is known as a meteorite. Meteorites are a sort of stones from the sky.** By studying the composition of meteorites we can get valuable information about the nature of the material from which the solar system was formed. It should be noted that the number of meteorites striking the moon's surface is quite large whereas very few meteorites reach the earth's surface. This is due to the fact moon has no atmosphere to burn the falling meteorites by producing the frictional heat.

7. The Shape of the Earth

In ancient times, people believed that the shape of the Earth was flat and it had steep edges. Today we know that the Earth is almost spherical. However, it is not a perfect sphere, rather it an **oblate spheroid**, bulging slightly at the equator and flattened slightly at the poles. The

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difference between the equatorial diameter and the polar diameter is less than 44 km. The diameter of the Earth is 12,756 km at the equator, whereas it is 12,712 km between the poles.

This is due to the centrifugal force caused by the Earth's rotation around its axis. This difference is insignificant and thus for all practical purposes the Earth is taken as spherical in shape.

The view that the Earth is spherical in shape was first forwarded by the famous Greek philosopher, Phagoras, in the sixth century BC. But people did not believe him. Later, Aristotle, Varahamihira, Aryabhata and Copernicus also opined that the Earth is spherical in shape.

7.1. Evidence of the Earth's Sphericity

There are many ways to prove that earth is spherical. The following are some of them.

1. The Sun and the other planets in the Solar System are all spherical in shape.
2. If the Earth was flat, then all the places on the Earth would have had sunrise and sunset exactly at the same time.
3. If we watch a ship approaching the land, first we see the smoke of the ship (as the entire ship lies below the line of sight) and gradually the entire ship, as it comes up over the horizon. If the Earth was flat, we would have been able to see the whole ship at a time.
4. A circular shadow observed during the lunar eclipse can only be cast by a spherical body.
5. If you look around from any place, whether a mountain, a level plain, or top of a very tall building, the horizon will always appear circular. This is possible only in case of a spherical body.
6. Magellan's circumnavigation in 1520 proved that the Earth is spherical in shape.
7. Engineers when driving poles of equal length at regular intervals on the ground have found that they do not give a perfect horizontal level. The centre pole normally projects slightly above the poles at either end because of the curvature of the earth.
8. Nowadays, when you can see the Earth in its true perspective from the outer space, the fact that the shape of the Earth is spherical needs no further proof.

Goldilocks zone

A **habitable zone**, also called a Goldilocks zone, is the region around a star where orbiting planets similar to the Earth can support liquid water. It is neither too hot, nor too cold.

Scientists hunting for life in the Solar System and around other stars believe liquid water is an important ingredient necessary for life.

In September 2010 astronomers using the Keck telescope announced they had found an exoplanet, Gliese 581g[2], about three times the size of Earth in the habitable zone of its star.

The Earth is a unique planet because it sustains life. Here are some more details:

1. The Earth lies between the orbits of Venus and Mars and the average distance from the Sun is about 148 million km. This gives it the optimum location with reference to the distance from the Sun. It is neither too hot like Venus nor too cold like Mars and the outer planets. The average temperature is about 17°C on the side facing the Sun.
2. The Earth has a favourable environment and presents optimum conditions for the origin, growth and survival of various life forms. If the heat received from the Sun

[2] UPSC asked question on Gliese 581g

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(insolation) increases or decreases by about 10 per cent, then a very large part of the Earth would become unsuitable for living organisms.

3. The rotation of the Earth around its axis, helps in keeping the extremes of temperatures between day and night well within tolerable limits.
4. The presence of adequate quantities of water in the oceans, seas, gulfs, rivers, lakes, etc., is a unique feature of our planet. Water occupies about 71 per cent of the total surface area of the Earth. These water bodies provide Ideal conditions for the origin and evolution of various life forms. The water cycle maintains the continuous flow of water on Earth.
5. The atmosphere acts as a shield and protects our planet from the harmful ultra-violet rays coming from the Sun. The atmosphere also absorbs terrestrial radiation from the Earth's surface and thus keeps the Earth comparatively warmer during the night time and also during the winter season.
6. The presence of oxygen in the atmosphere has made life possible on Earth, as it is essential for respiration and survival of all living organisms.

7.2. The Earth's Movement

Origin of Life on Earth

Modern scientists refer to the origin of life as a kind of chemical reaction, which first generated complex organic molecules and assembled them. This assemblage was such that they could duplicate themselves converting inanimate matter into living substance. The record of life that existed on this planet in different periods is found in rocks in the form of fossils. The microscopic structures closely related to the present form of blue algae have been found in geological formations that are much older than these were some 3,000 million years ago. It can be assumed that life began to evolve sometime 3,800 million years ago. The summary of evolution of life from unicellular bacteria to the modern man is given in the Geological Time Scale on last page.

In the Solar System, the Earth has a special relationship with the Sun and the Moon. The Earth revolves around the Sun, and the Moon revolves around the Earth. The Earth also rotates on its axis.

These motions of the Earth cause **days and nights**, **seasons**, **tides**, **eclipses**, etc.

7.2.1. Day and Night

When the earth rotates on its own axis, only one portion of the earth's surface comes into the rays of the sun and experiences daylight. The other portion which is away from the sun' rays will be in darkness. As the earth rotates from west to east, every part of the earth's surface will be brought under the sun at some time or other, a part of the earth's surface that emerges from darkness into the sun's rays experiences sunrise. Later, when it is gradually obscures from the sun is in fact, stationary and it is the earth which rotates. The illusion is exactly the same as when we travel in a fast- moving train. The trees and houses around us appear to move and we feel that the train is stationary.

7.2.2. The Earth's Revolution

When the earth revolves round the sun, it spins on an elliptical orbit and one complete revolution takes 365¼ days or a year. As it is not possible to show a quarter of a day in the calendar, a normal year is taken to be 365 days, and an extra day is added every four years as a Leap Year.

The Earth rotates once in about 24 hours with respect to the sun and once every 23 hours 56 minutes and 4 seconds **with respect to the stars**. This is the reason why the stars rise four minutes early every next day. Earth's rotation is slowing slightly with time; thus, a day was

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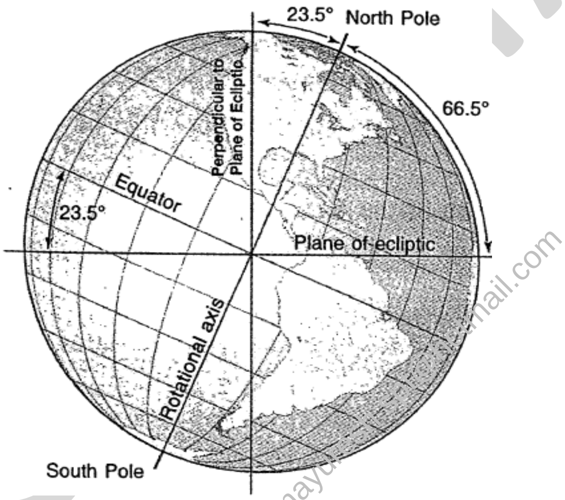
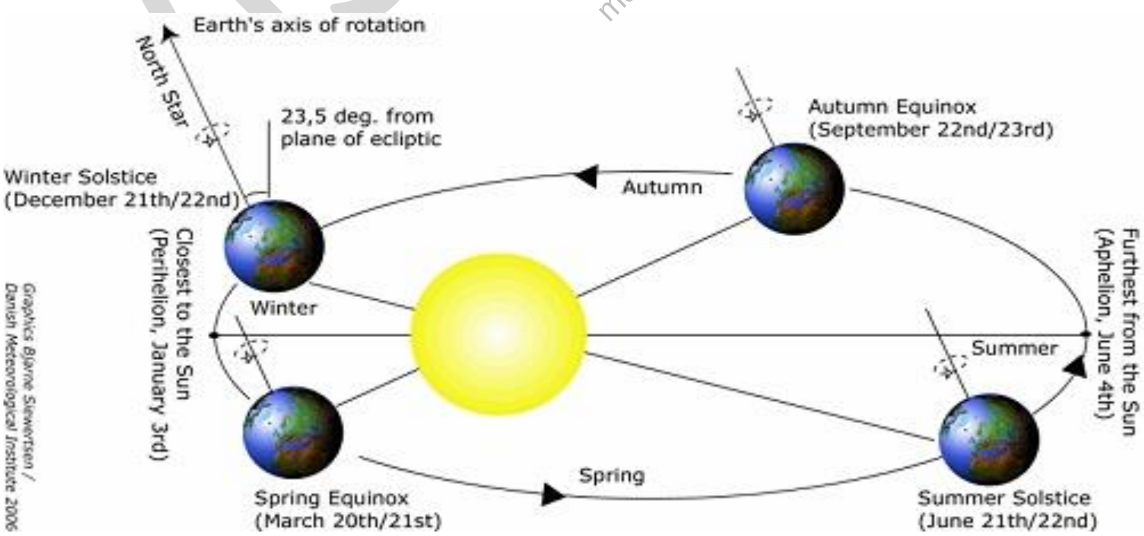
shorter in the past. This is due to the tidal effects the Moon has on Earth's rotation. Atomic clocks show that a modern day is longer by about 1.7 milliseconds than a century ago. Leap seconds are used to synchronise atomic clock.

7.2.3. Varying Lengths of Day and Night

The axis of the earth is inclined to the plane of the ecliptic (the plane in which the earth orbits round the sun) at an angle of 66½°, giving rise to different seasons and varying lengths of day and night. If the axis were perpendicular to this plane, all parts of the globe would have equal days and night at all times of the year, but we know this is not so. In the hemisphere in winter as we go northwards, the hours of darkness steadily increase. At the Arctic Circle (66½°) the sun never 'rise' and there is darkness for the whole day in mid- winter on 22 December. Beyond the Arctic Circle the number of days with complete darkness increases, until we reach the North Pole (90°N) when half the year will have darkness. In the summer (June) conditions are exactly reversed. Daylight increases as we go polewards. At the Arctic Circle, the sun never 'sets' at mid-summer (21 June) and there is a complete 24-hour period of continuous daylight. In summer, the region north of the Arctic Circle is popularly referred to as "Land of the Mid-Night Sun'. At the North Pole, there will be six months of continuous daylight.

In the southern hemisphere, the same process takes place, except that the conditions are reversed. When it is summer in the northern hemisphere, the southern conditions will experience winter. Mid- summer at the North Pole will be mid-winter at the South Pole.





Revolution of Earth

7.2.4. The Altitude of the Midday Sun

In the course of a year, the earth's revolution round the sun with its axis inclined at 66½ to the plane of the ecliptic changes the apparent altitude of the midday sun. The sun is vertically overhead at the equator on two days each year. These are usually 21 March and 21 September though the date changes because a year is not exactly 365 days. These two days are termed equinoxes meaning ' equal nights' because on these two days all parts of the world have equal days and nights. After the March equinox the sun appears to move north and is vertically overhead at the Tropic of Cancer (23½°N) on about 21 June. This is known as the June or summer solstice when the northern hemisphere will have its longest day and shortest night. By about 22 December, the sun will be overhead at the Tropic of Capricorn (23½°S). This is the winter solstice when the southern hemisphere will have its longest day and shortest night. The Tropics thus marks the limits of the overhead sun, for beyond these, the sun is never overhead at any time of the year. Such regions are marked by distinct seasonal changes- spring, summer, autumn and winter. Beyond the Arctic Circle(66½°N) and the Antarctic Circle (66½°S)where darkness lasts for 6 months and daylight is continuous for the remaining half of the year, it is always cold; for even during the short summer the sun is never high in the sky. Within the tropics, as the midday sun varies very little from its vertical position at noon daily, the four seasons are almost equal all the year round.

7.2.5. Seasonal Changes and their Effects on Temperature

Summer is usually associated with much heat and brightness and winter with cold and darkness. Why should this be so? In summer, the sun is higher in the sky than in winter. When the sun is overhead its rays fall almost vertically on the earth, concentrating its heat on a small area; temperature therefore rises and summer are always warm. In winter the oblique rays of the sun, come through the atmosphere less directly and have much of their heat absorbed by atmospheric impurities and water vapour. The sun's rays fall faintly and spread over a great area. There is thus little heat, and temperatures remain low.

In addition, days are longer than nights in summer and more heat is receives over the longer daylight duration. Nights are shorter and less heat is lost. There is a net gain in total heat received and temperature rise in summer. Shorter days and longer nights in winter account for the reverse effects.

7.2.6. Dawn and Twilight

The brief period between sunrise and full daylight is called dawn and that between sunset and complete darkness is termed twilight. This is caused by the fact that during the period the dawn and twilight the earth receives diffused or refracted light from the sun whilst it is still below the horizon. Since the sun rises and sets in a vertical path at the equator the period during which refracted light is received is short. But in temperate latitudes, the sun rises and sets in an oblique path and the period of refracted light is longer. It is much longer still at the poles, so that the winter darkness is really only twilight most of the time.

7.2.7. Eclipse

An eclipse occurs when the Sun, the Earth and the Moon are in a straight line in the plane of ecliptic. When the Earth obstructs the rays of the Sun from reaching the face of the Moon, the Moon gets eclipsed. When the Moon hides the face of the Sun, then it is an eclipse of the Sun.

At anytime the Sun is able to light only half of the Earth's surface which is facing the Sun. The other half, which is turned away from the Sun is in darkness.

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7.2.7.1. Lunar Eclipse

A lunar eclipse will occur, only when the Sun, the Earth and the Moon are in a straight line, and the Earth lies between the Sun and the Moon. This is possible on a Full Moon day. But a lunar eclipse does not occur on every Full Moon day, as these three bodies have to be in the plane of ecliptic.

(a) If the Moon is exactly in the plane of ecliptic, a total lunar eclipse will occur.
(b) If the Moon is close to the plane of ecliptic, a partial lunar eclipse will occur.
(c) If the Moon is far above or far below the plane of ecliptic, no eclipse will occur.

7.2.7.2. Solar Eclipse

A solar eclipse will occur only when the Sun, the Earth and the Moon are in a straight line, and the Moon lies between the Sun and the Earth. This is possible on a New Moon day. But the solar eclipse does not occur on every New Moon day, as these three bodies have to be in the plane of ecliptic.

(a) If the Moon is exactly in the plane of ecliptic, a total solar eclipse will occur.
(b) If the Moon is close to the plane of ecliptic, a partial solar eclipse will occur.
(c) If the Moon is far above or far below the plane of ecliptic, no eclipse will occur.

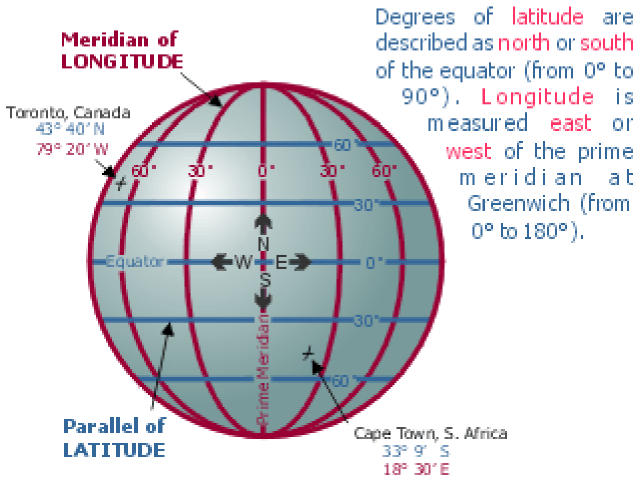
The Diamond Ring Effect is a visual phenomenon that occurs during a total solar eclipse. It is seen from earth when standing in the umbra of the moon's shadow, and occurs as a part of Baily's Beads. Baily's Beads are glimmers of the sun's brilliant surface (the photosphere) which shine as dots of light around the disc of the lunar shadow. When only one "bead" remains, momentarily, the view of the eclipse resembles a diamond ring. The ring is produced as the sun's less bright corona layer and other upper atmospheric structures remain dimly visible as a solid ring while a dazzling dot of the photosphere shines at the edge.

8. The Geographical Grid- Latitude and Longitude

The earth's surface is so vast that unless a mathematical method can be used, it is impossible to locate any place on it. For this reason, imaginary lines have been drawn on the globe. One set running east and west, parallel to the equator, are called lines of latitude. The other set runs north and south passing through the poles and are called lines of longitude. The intersection of latitude and longitude pin-points any place on the earth's surface. For example Delhi is 28°37'N and 77°10'E.

8.1. Latitude

Latitude is the angular distance of a point on the earth's surface, measured in degrees from the centre of the earth. It is parallel to a line, the equator, which lies midway between the poles. These lines are therefore called parallels of latitude, and on a globe are actually circles, becoming smaller polewards. The equator represents 0° and the North and South Poles are 90°N and 90°S. Between these points lines of latitude are drawn at intervals of 1°. For precise location on a map, each degree is sub-divided into 60 minutes and each minute into 60 seconds. The most important lines of latitude are the equator, the tropic of Cancer (23½°N.), the tropic of Capricorn (23½°S.), the Arctic Circle (66½°N.) and the Antarctic Circle (66½°S.). As the earth is slightly flattened at the poles, the linear distance of a degree of latitude at the pole is a little longer than that at the equator. For example at the equator (0°) it is 68.704 miles, at 45° it is 60.054 miles and at the poles it is 69.407 miles. The average is taken as 69 miles. This is a useful figure and can be used for calculating distances to any place. Bombay is 18.55°N; it is therefore 18.55*69 or 1280 miles from the equator.



Latitude and Longitude

8.2. Longitude

Longitude is an angular distance, measured in degrees along the equator east or west of the Prime (or First) Meridian. On the globe longitude is shown as a series of semi-circles that run from pole to pole passing through the equator. Such lines are also called meridians. Unlike the equator which is centrally placed between the poles, any meridian could have been taken to begin the numbering of longitude. It was finally decided in 1884, by international agreement, to choose as the zero meridian the one which passes through the Royal Astronomical Observatory at Greenwich, near London. This is the Prime Meridian (0°) from which all other meridians radiate eastwards and westwards up to 180°. Since the earth is spherical and has a circumference calculated at 25,000 miles, in liner distance each of the 360 degrees of longitude is 25,000/360 or 69.1 miles. As the parallels of latitude become shorter polewards, so the meridians of longitude, which converge at the poles, enclose a narrower space. The degree of longitude therefore decreases in length. It is longest at the equator where it measures 69.172 miles. At 25° it is 62.73 miles, at 45° it is 49 miles, at 75° 18 miles and at the pole 0 mile. There is so much difference in the length of degrees of longitude outside the tropics, that they are not used for calculating distances as in the case of latitude. But they have one very important function; they determine local time in relation to G.M.T or Greenwich Mean Time, which is sometimes referred to as World Time.

8.3. Longitude and Time

Local time: Since the Earth makes one complete revolution of 360° in one day or 24 hours, it passes through 15° in one hour or 1° in 4 minutes. The earth rotates from west to east, so every 15° we go eastward, local time is advanced by 1 hour. Conversely, if we go westwards, local time is retarded by 1 hour. We may thus conclude that places east of Greenwich see the dun earlier and gain time, whereas places west of Greenwich see the sun later and lose time. If we know G.M.T., to find local time, we merely have to add or subtract the difference in the number of hours from the given longitude, as illustrated below. A simple memory aid for this will be East-Gain-Add (E.G.A.) and West-Lose-Subtract (W.L.S.). You could coin your own rhymes for the abbreviations. Hence when it is noon, in London (Longitude 0°5W.), the local time for Chennai (80°E.) will be 5 hours 20 minutes ahead of London or 5.20 p.m. but the local time for New York (74°W.) will be 4 hours 56 minutes behind London or 7.04 a.m.

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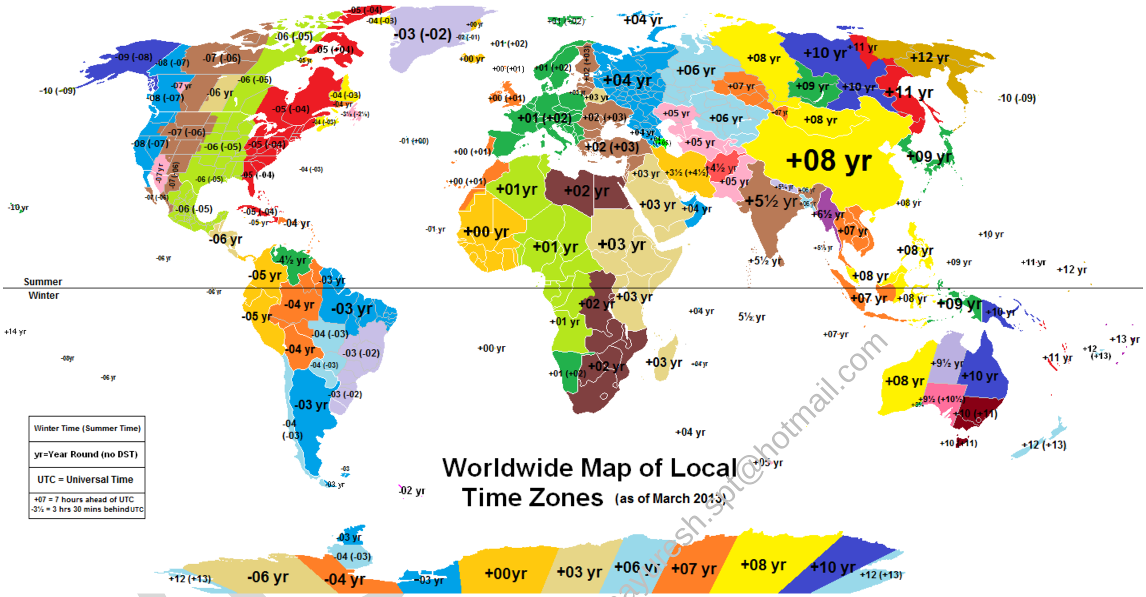
8.4. Standard Time and Time Zones

If each town were to keep the time of its own meridian, there would be much difference in local time between one town and the other. 10 a.m. in Georgetown, Penang would be 10.10 in Kota-Bharu (a difference of 2½° in longitude). In larger countries such as Canada U.S.A., China, India, and Russia the confusion arising from the differences alone would drive the people mad. Travellers going from one end of the country to the other would have to keep their appointments. This is impracticable and very inconvenient.

To avoid all these difficulties, a system of standard time is observed by all countries. Most countries adopt their standard time from the central meridian of their countries. The Indian Government has accepted the meridian of 82.5° east for the standard time which is 5hrs. 30 minutes ahead of Greenwich Mean Time. The whole world has in fact been divided into 24 Standard Time Zones, each of which differs from the next by 15° in longitude or one hour in Time. Most countries adhere to this division but due to the peculiar shapes and locations of some countries, reasonable deviations from the Standard Time Zones cannot be avoided.

Larger countries like U.S.A. (9), Canada (6) and Russia (9) which have a great east-west stretch have adopted 9, 6 and 9 time zones respectively for practical purposes.



Daylight saving time (DST) is a change in the standard time with the purpose of getting better use of the daylight. Typically, clocks are adjusted forward one hour near the start of spring and are adjusted backward in the autumn. Although it has only been used in the past hundred years, the idea of DST was first conceived many years before.

9. Geological Time Scale

The earth is believed to be 4.5 billion years old. The 4.5 billion year long history of the earth is divided into four era - Pre-Cambrian, Palaeozoic, Mesozoic and Calnozoic. Pre-Cambrian has been the longest era in the earth's history and it continued from the origin of earth to about 600 million year ago from today. The eras are divided into periods, and the periods are divided in to epochs. A brief account of the geological history of the earth is given in the following table:

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Eons	*Era*	*Period*	*Epoch*	*Age/Years Before Present*	*Life/ Major Events*
	Cainozoic (From 65 million years to the present times)	Quaternary	Holocene Pleistocene	0 - 10,000 10,000 - 2 million	Modern Man Homo Sapiens
		Tertiary	Pliocene Miocene Oligocene Eocene Palaeocene	2 - 5 million 5 - 24 million 24 - 37 Ma 37 - 58 Million 57 - 65 Million	Early Human Ancestor Ape: Flowering Plants and Trees, Anthropoid Ape Rabbits and Hare Small Mammals : Rats – Mice
	Mesozoic 65 - 245 Million Mammals	Cretaceous Jurassic Triassic		65 - 144 Million 144 - 208 Million 208 - 245 Million	Extinction of Dinosaurs Age of Dinosaurs Frogs and turtles
	Palaeozoic 245 - 570 Million	Permian Carboniferous Devonian Silurian Ordovician Cambrian		245 - 286 Million 286 - 360 Million 360 - 408 Million 408 - 438 Million 438 - 505 Million 505 - 570 Million	Reptile dominate-replace amphibians First Reptiles: Vertebrates: Coal beds Amphibians, First trace of life on land: Plants, First Fish No terrestrial Life: Marine Invertebrate
Proterozoic Archean Hadean	Pre- Cambrian 570 Million - 4,800 Million			570 - 2,500 Million 2,500 - 3,800 Million 3,800 - 4,800 Million	Soft-bodied arthropods Blue green Algae: Unicellular bacteria Oceans and Continents form – Ocean and Atmosphere are rich in Carbon dioxide
Origin of Stars Supernova Big Bang	5,000 - 13,700 Million			5,000 Million 12,000 Million 13,700 Million	Origin of the sun Origin of the universe

Questions:

1. Gliese 581g (UPSC 2011/2 Marks)
2. What does the solar system consists of? Discuss the motion of the entire solar system as a whole and also the motion of most of the bodies forming the solar system. (UPSC 2003/ 15 Marks)
3. What is the difference between a comet and a meteor? (UPSC 1997/3 Marks)
4. Why does a lunar eclipse occur only on a full moon? (UPSC 1996/3 Marks)
5. What is a leap second? (UPSC 1992/3 Marks)
6. What is 'Chandrashekhar limit'? (UPSC 1985/3 Marks)
7. Astronomers have, of late, been discussing 'black hole.' What is a 'black hole'?(UPSC 1979/3 Marks)
8. What is the 'diamond ring effect' observed during a total solar eclipse? How is it caused? (UPSC 1979/3 Marks)

Student Notes:

INTERIOR OF EARTH

Contents

Student Notes:

1. Introduction

Human life is largely influenced by the physiography of the region. Therefore, it is necessary that one gets acquainted with the forces that influence landscape development. Also to understand why the earth shakes or how a tsunami wave is generated, it is necessary that we know certain details of the interior of the earth.

2. Sources of Information

Most of the information about the Earth's interior is based on inferences drawn from different sources – both direct and indirect.

2.1. Direct Sources

Our knowledge about the structure and interior of the earth from direct observation is very limited. No instrument has been invented so far which can see through the interior of the earth directly. The deepest depth of an oil well drilled so far is 8 kilometers. The deepest mine of the world is Robinson Deep in South Africa. Its depth is less than 4 kilometer.

Besides mining, scientists have taken up a number of projects to penetrate deeper depths to explore the conditions in the crustal portions. Scientists world over are working on two major projects such as "Deep Ocean Drilling Project" and "Integrated Ocean Drilling Project". The deepest drill at Kola, in Arctic Ocean, has so far reached a depth of 12 km. This and many deep drilling projects have provided large volume of information through the analysis of materials collected at different depths.

Volcanoes are yet another major source of direct information – they tell us about the composition and characteristics of the materials found inside the Earth. However, it is difficult to ascertain the depth of the source of such material.

2.2. Indirect Sources

The centre of the earth downward is 6,371 kilometers away from the surface of the earth. In comparison to this distance the depth of a deep well or a mine is insignificant. It is therefore, necessary to take help of indirect scientific evidences to know about the interior of the earth. These sources include temperature, pressure and density of earth, behaviour of seismic waves (the waves generated by Earthquakes), Meteors, the Moon etc. These sources may be classified into three groups

(a) Artificial sources such as temperature, pressure and density.
(b) Evidences from the theories of origin of earth
(c) Natural Sources e.g. volcanic eruption, earthquakes, meteors and seismology.

2.2.1. Temperature

Temperature goes on increasing with the increase in depth inside the earth. This is clearly proved while going down a mine or deep wells. The volcanic eruptions or hot water springs also confirm this fact that temperature increasing towards the interior of the earth. On an average, there is a rise of 1°C temperature for every 32 meters of depth. This rapid increase in temperature continues to great depth there after the temperature increases slowly.

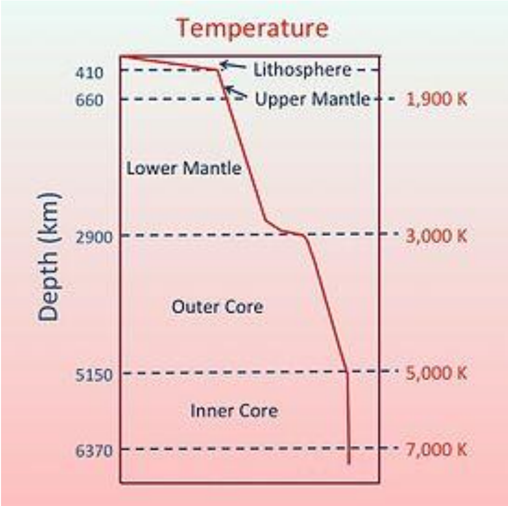


Fig 1: Temperature profile of the inner Earth

The main reasons for the increase in heat and temperature in the interior of the earth are the following:

1. Radioactive disintegration within rocks which liberates heat
2. Internal and external forces (gravitational pull, weight of overlying rocks etc.)
3. Chemical reactions

It is tempting to think that under the conditions of this enormous temperature in the interior of the earth nothing can be found in solid state. Under such conditions all existing rocks should be either in liquid or gaseous state. But it is not so. Along with the increase in temperature with depth, pressure too increases in the interior of the earth. This pressure is lacs of times more than the pressure exercised by atmospheric layers on the surface of the water in oceans. For this reason due to enormous pressure, liquid state rocks of the core have the properties of solids. It is possible that these rocks might be in plastic state. It is why these rocks have elasticity. Due to the pressure of overlying layers on the earth's interior these rocks do look solid upto 2900 kilometers' depth. Sometimes due to lessening of overlying pressure, the rocks in the interior melt down and the fluid comes to the surface or is in the process of finding its way to the surface of the earth. A volcanic eruption is one such example.

2.2.2. Density

In accordance with the Newton's laws of gravity the earth's density has been calculated to be 5.5 (gms per cubic centimeter). However, it is surprising that the rocks near the surface of the earth have an average density of 2.7 only (gms per cubic centimeter). This density is less than half the average density of the earth as a whole. From this, it is clear that the **density too increases with the increase in depth**. The earth's internal part is composed of very dense rocks; their density must be in the range of 8-10 (gms per cubic centimeter). The density of the central part of the core is still more.

Higher density could be due to heavy metals like Nichel and Iron at the centre as well as due to pressure of overlying layers.

2.2.3. Pressure

Just like temperature and density and pressure too increase with increase in depth inside the earth. Some earth scientists believe that due to the weight of the overlying layers the pressure goes on increasing with depth and others think that materials of the interior of the earth are heavier since birth of the earth. The happenings due to change in pressure inside the earth affect the physical features on the surface of the earth.

Student Notes:

2.2.4. Gravitation force

The gravitation force (g) is not the same at different latitudes on the surface. It is greater near the poles and less at the equator. This is because of the **distance** from the centre at the equator being greater than that at the poles. The gravity values also differ according to the **mass of material**. The uneven distribution of mass of material within the earth influences this value. The reading of the gravity at different places is influenced by **many other factors**. These readings differ from the expected values. Such a difference is called **gravity anomaly**. Gravity anomalies give us information about the distribution of mass of the material in the crust of the earth. Gravity anomalies also inform us about the distribution of molten material in the crust of the earth.

2.2.5. Magnetic surveys

The earth also acts like a huge magnet. The rapid spinning of earth creates electric currents in its centre (molten outer core) that creates a magnetic field around the earth. The magnetic field is strongest at the magnetic north and south poles. The magnetic north and south poles do not coincide with geographic north and south poles. In fact, the earth's magnetic field keeps on changing. Magnetic surveys provide information about the distribution of magnetic materials in the crustal portion, and thus, provide information about the distribution of materials in this part.

2.2.6. Meteorites

The space debris, while entering the atmospheric layers of earth are burnt due to the friction of air. Only the heavier objects whose outer layers have been burnt fall to the earth. Man has discovered many such meteorites and after examining them obtained evidences about the interior of the earth. The meteorites which have been examined are of two types: (i) Rock; and (ii) Metals.

The metallic meteorites chiefly contain heavy materials like iron and nickel. The meteorites too have originated during the formation of solar system. It is, therefore, very much in order to believe that both the meteorites and the earth are made of similar materials.

2.2.7. The Moon

The first information about the earth's interior had been obtained through the study of the moon. There are several ways of determining the moon's orbit around earth. Among these one of the important factors is earth's mass. Remember, there is close relationship between the mass and earth's gravitation. The movements of the moon and its distance from earth provide the basis for determining the mass of the earth by earth scientists.

2.2.8. Evidence from Theories

The earth was mostly in a volatile state during its primordial stage. Due to gradual increase in density the temperature inside has increased. As a result the material inside started getting separated depending on their densities. This allowed heavier materials (like iron) to sink towards the centre of the earth and the lighter ones to move towards the surface. With passage of time it cooled further and solidified and condensed into a smaller size. This later led to the development of the outer surface in the form of a crust. During the formation of the moon, due to the giant impact, the earth was further heated up. It is through the process of differentiation that the earth forming material got separated into different layers. Starting from the surface to the central parts, we have layers like the crust, mantle, outer core and inner core. From the crust to the core, the density of the material increases. We shall discuss in detail the properties of each of this layer in the next chapter.

2.2.9. Earthquake Waves

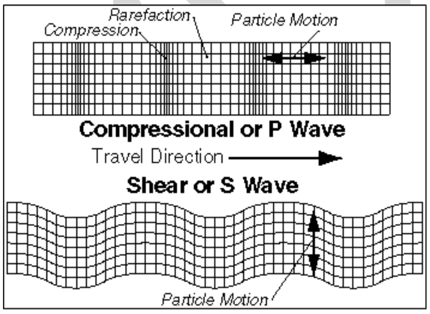
Earthquakes[1] are caused by the movements in the interior of the earth. These movements cause waves inside the earth just as waves are generated on the surface of water in a lake when a stone is thrown into it. Incidentally, majority of the earthquakes originate in the upper mantle.

The earthquake waves are measured on the seismograph. The study of earthquake waves helps earth-scientists to get a lot of information about the types of rocks and layered composition in the interior of the earth.

Earthquake waves are basically of two types — body waves and surface waves. Body waves are generated due to the release of energy at the focus (origin of earthquake) and move in all directions travelling through the body of the earth. Hence, the name body waves. The body waves interact with the surface rocks and generate new set of waves called surface waves. These waves move along the surface. The velocity of waves changes as they travel through materials with different densities. The denser the material, the higher is the velocity. Their direction also changes as they reflect or refract when coming across materials with different densities.

There are two types of body waves: P-waves and S-waves. Important surface waves are Rayleigh waves and L-waves (named after A. E. H. Love).

Body Waves		**Surface Waves**
'P'- Waves' or Primary waves	**'S'- Waves' or Secondary waves**	**L-waves**
I. These are '**Longitudinal** Waves'. II. Under their influence particles are displaced in backward-forward direction. (compression waves.) III. Their velocity is the fastest. IV. Their average velocity is 6-15 kilometers per second. V. Different densities of rocks have different velocities. VI. They can travel through all mediums – solids, liquids and gases.	I. These are **transverse** waves. II. Under their impact particles swing side by side (shear waves). III. Their velocity is lower than the primary waves. IV. These waves cannot pass through liquids. They travel through **solids only**.	I. These are **transverse** waves. II. Their propagation is limited to the surface of the earth only. III. Their velocity through solid particles or rocks is about 3.5 kilometers per second. IV. They cause the greatest damage and destruction of property during the earthquake.



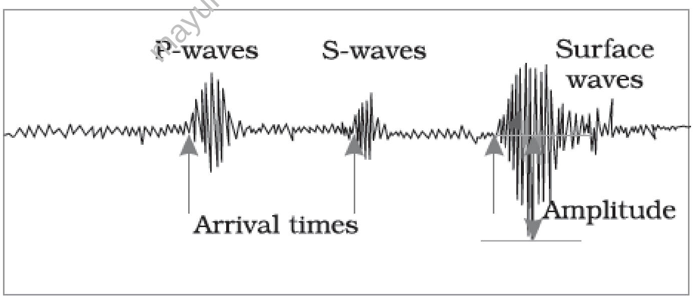


Fig 2: Particle motion in seismic waves **Fig 3: Arrival time of seismic waves**

[1] Note: Earthquakes, Richter scale, epicenter, hypocenter etc. will be discussed in another chapter.

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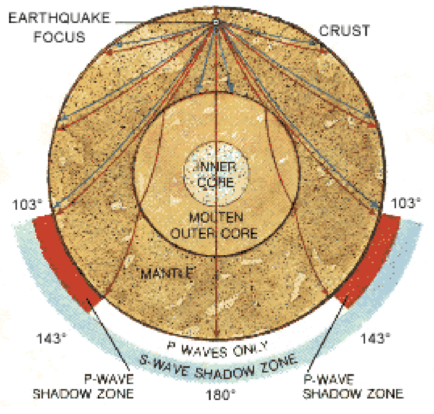


Fig4: Shadow Zones

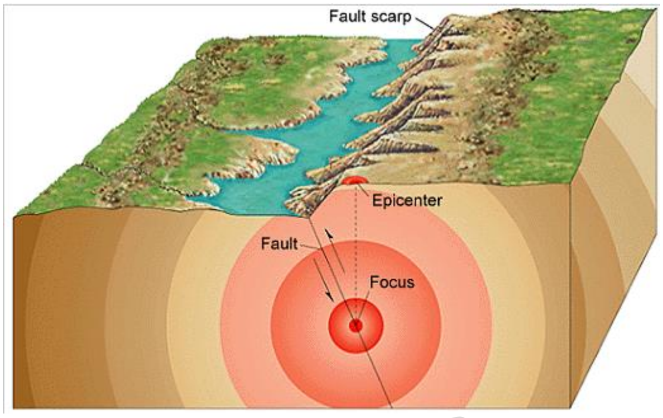


Fig 5: Earthquake

3. Structure of the Earth's Interior

The earthquake waves undergo changes at definite intervals during their propagation through the interior of the earth. They also undergo the action of reflection and refraction. Places on earth where seismic waves are not recorded are called "shadow zones". S-waves are not recorded beyond 103^o angular distance from focus which indicate that outer core of earth is in molten or semi-molten in which S-waves cannot propagate. As P-waves are not recorded between angular distances of 103^o to 142^o, it indicates that the core has different density, state and composition.

From the analysis of the behavior of these waves it is clear that the interior of the earth has a layered structure of different densities.

With the help of earthquake waves, we can get the information about the exact location of the layers, their depth, thickness and other physical and chemical properties. Based on the passage of these waves through different types of rocks and their behavior we can conclude that the earth's interior has three main layers. These three layers are: (i) Crust, (ii) Mantle and (iii) Core. This arrangement can be compared to that of a boiled egg.

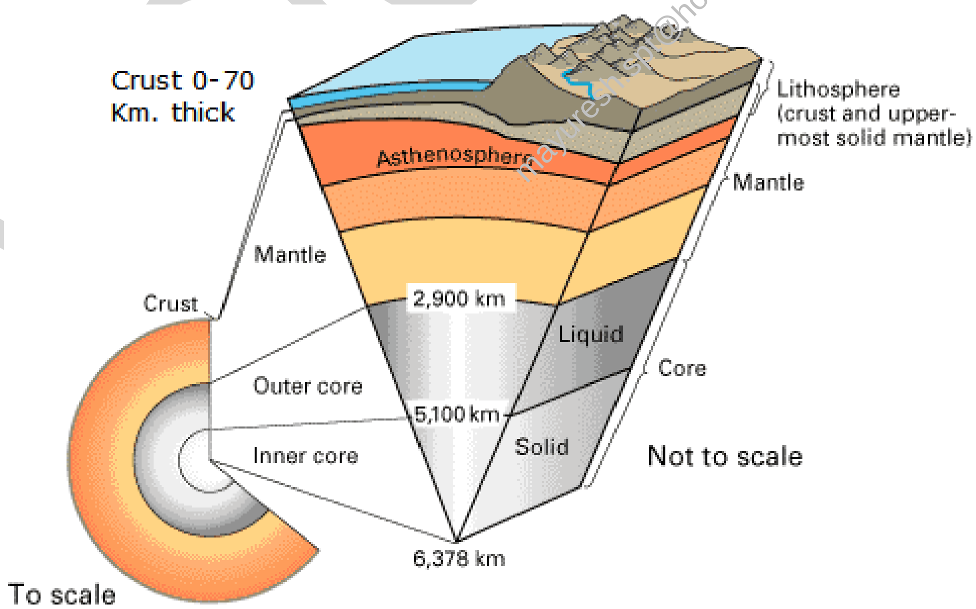


Fig 6

Student Notes:

3.1. The Crust

It is the earth's uppermost layer. Crust is solid, rigid and very thin compared with the other two. Like the shell of an egg, the Earth's crust is brittle and can break. The thickness of the crust is not same everywhere.

Oceanic crust is thinner as compared to the continental crust. The mean thickness of oceanic crust is 5 km whereas that of the 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.

Its two main parts are:

1. The uppermost thin layer– It is composed of such rocks which contain a large proportion of silica and aluminum. It is called **SIAL** (SI = Silica, AL = Aluminum). The continents are mostly composed of sial. It average density is 2.7 and thickness is of about 28 kilometers.
2. The lower layer of the crust is made of comparatively heavier rocks. Silica and magnesium are the major constituents in it. This part is therefore, known as **SIMA** (SI – Silicon, MA = Magnesium). The oceanic floor is also made of this rock strata. Its average thickness is 6-7 kilometers and density of about 3.0.

The thickness of SIAL and SIMA put together does not exceed 70 kilometers. Its volume is 1% of the total volume of the earth. In comparison to 6378 km radius of the earth, the thickness of 70 kilometers is insignificant. However, this cannot be over looked. This shallow crust is the ground of the nature's wonderful activities.

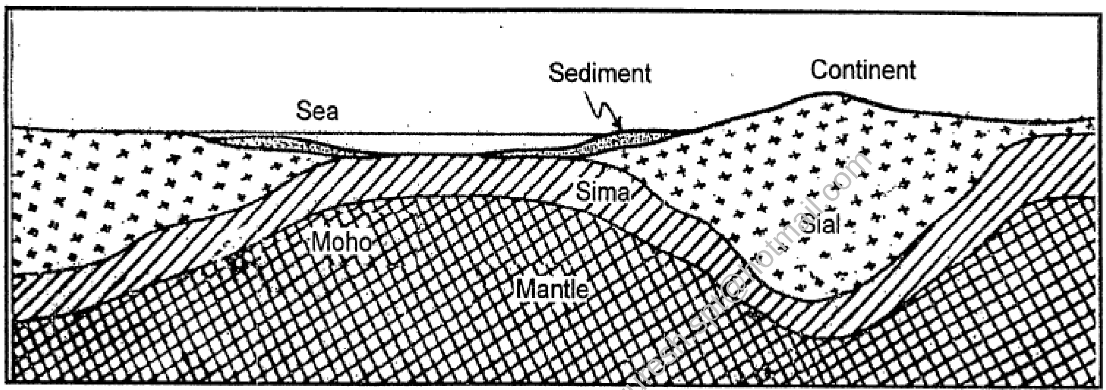


Fig 7: Earth Crust

3.2. The Mantle

Its thickness is about 2900 Km. It volume is 83% of the whole earth. Near the lower limit of the crust the velocity of P-waves increases from about 6.4 kilometers per second to 8 km per second. This change in velocity of P-waves indicates the **surface discontinuity between the crust and the mantle**. It is popularly known as Moho or the Mohorovicic discontinuity (after the name of its discoverer).

The mantle is made up of dense and heavy materials such as oxygen, iron and magnesium. The average density of the materials in the mantle varies between 3.5 g per cubic cm and 5.5 g per cubic cm. The temperature of this layer ranges between 900°C and 2200° C. The temperature is quite high and the hot rocks form magma in this layer. The pressure of the overlying layers, keeps the lower part of the crust and the upper part of the mantle in an almost solid state. If cracks appear in the crust, the pressure is released and the molten matter from inside the Earth tries to reach the surface through volcanic eruptions.

Student Notes:

The upper portion of the mantle is called **asthenosphere**. The word astheno means weak. It is considered to be extending upto 400 km. It is the main source of magma that finds its way to the surface during volcanic eruptions.

The mantle plays an important role in all the happenings in the interior of the earth. It also gives rise to Convection Currents. These currents supply energy for happenings like continental drift, earthquake, volcanoes, etc.

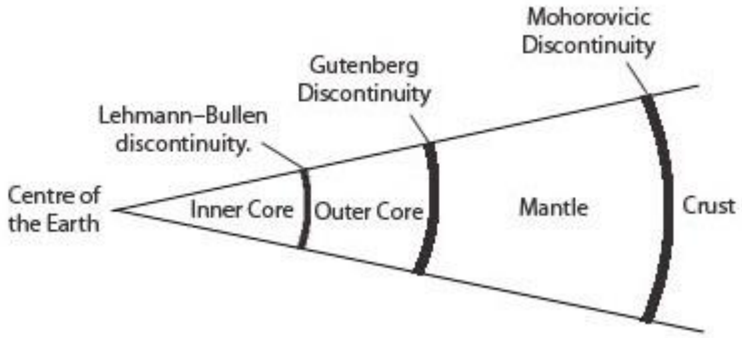


Fig 8: The Discontinuities

3.3. The Core

It extends from 2900 Km depth upto the centre of the earth (6378 km). It is the interior most part of the earth. It begins from Gutenberg Discontinuity. The mantle is demarcated from the core by Gutenberg Discontinuity. The core is divided into two parts: (i) The Outer Core, (ii) The Inner Core.

The outer core is possibly in wholly liquid or semi-liquid state. The transverse or S-waves of earthquakes, seem to disappear at the Gutenberg Discontinuity. The outer core extends from the depth of 2900 km, upto 5150 km. It has an average density of 10. The inner core is believed to be solid. It extends from the depth of 5150 km upto the centre of the earth (6378 km). The velocity of P waves increases at the boundary of outer and inner core. Its density is between 12-13. To volume of the entire core is 16% of earth as a whole. The mass of the core is 32% of the earth's mass. The major part of the core is made up of heavy metals like iron and nickel. This zone is therefore known as Nife (Ni = Nickel, Fe = Ferrous). It is also known as Barysphere (which means heavy metallic rocks).

Table 3.1

Name of the Layer	Chemical Composition	Depth	Density	Physical Property
A. Crust 1. Upper SIAL 2. Lower SIMA	Crustal material contains lighter elements like Si, O, Al, Ca, K, Na, etc... Feldspars (Anorthite, Albite, Orthoclase) are common minerals in the crust ($CaAL_2Si_2O_8$, $NaALSi_3O_8$, $KALSi_3O_8$).	5-70 Km.	2.75 – 2.90	Solid State
B. Mantle 3. upper mantle (From Moho to 410 km) 4. transition zone (410–660 km), 5. lower mantle (660–2891 km)	is made up of Si and O, like the crust, but it contains more Fe and Mg. Thus, Olivine (Fe_2SiO_4-Mg_2SiO_4) and pyroxene ($MgSiO_3$-$FeSiO_3$) are abundant in the mantle	35-2900 km.	3.4-5.6	Some properties of solid, some plastic. Near the melting point their behavior is like solids heavy

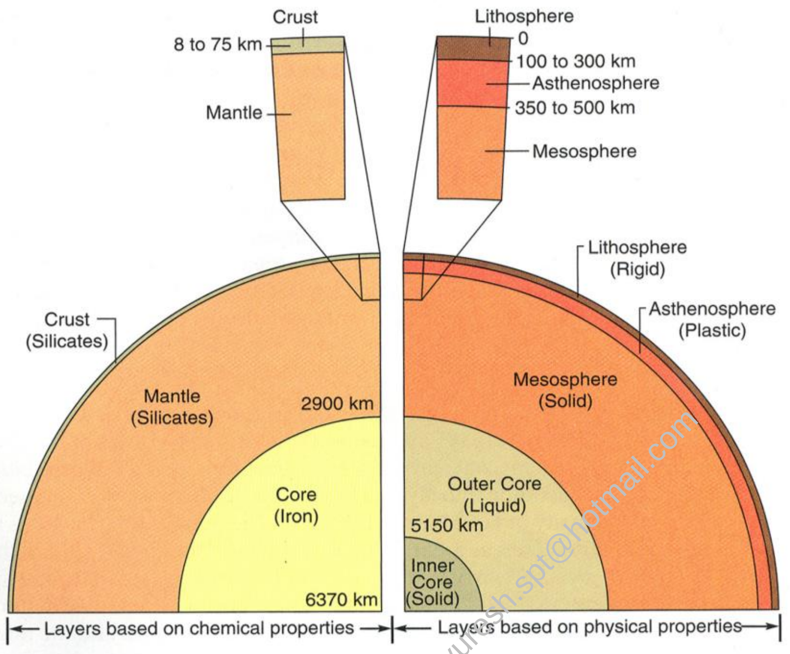
Student Notes:

C. Metallic Core of Barysphere 6. Outer Metallic Core 7. Inner Metallic Core	NIFE (Nickel + Ferrous or Iron) Barysphere (Heavy Metallic rocks)	2900 – 5150 km 5150 – 6378 km	5.10 – 13.00	Liquid or in plastic state Rigid because of tremendous overlying pressure

4. Crust and Mantle vs. Lithosphere and Asthenosphere

Lithosphere, asthenosphere, and mesosphere represent changes in the mechanical properties of the Earth. Crust, Mantle and Core refer to changes in the chemical composition of the Earth.

The lithosphere (litho: rock; sphere: layer) is the strong, upper 100 km of the Earth. The lithosphere is the tectonic plate (we talk about it in plate tectonics). The asthenosphere (asthenos: weak) is the weak and easily deformed layer of the Earth that acts as a "lubricant" for the tectonic plates to slide over. The asthenosphere extends from 100 km depth to 660 km beneath the Earth's surface. Beneath the asthenosphere is the mesosphere, another strong layer.



Student Notes:

CONTINENTAL DRIFT AND PLATE TECTONICS

Contents

EARTH OF THE DISTANT PAST WAS A VERY DIFFERENT PLANET THAN THE ONE WE KNOW TODAY

1. Supercontinent

If you could travel through time to arrive at the Earth of a billion years ago, you would have a hard time navigating. A strange giant continent and a single planetary ocean would replace the familiar continents and oceans of today's world. A supercontinent is the assembly of most or all the Earth's continental blocks to form a single large landmass. There is no unanimity among tectonicists on a single definition of supercontinent. Hoffman (1999) used the term "supercontinent" to mean "a clustering of nearly all continents". According to this definition, Pangaea is a supercontinent while Gondwana is not. There are other scholars who consider Gondwanaland a supercontinent of pre-Cambrian period.

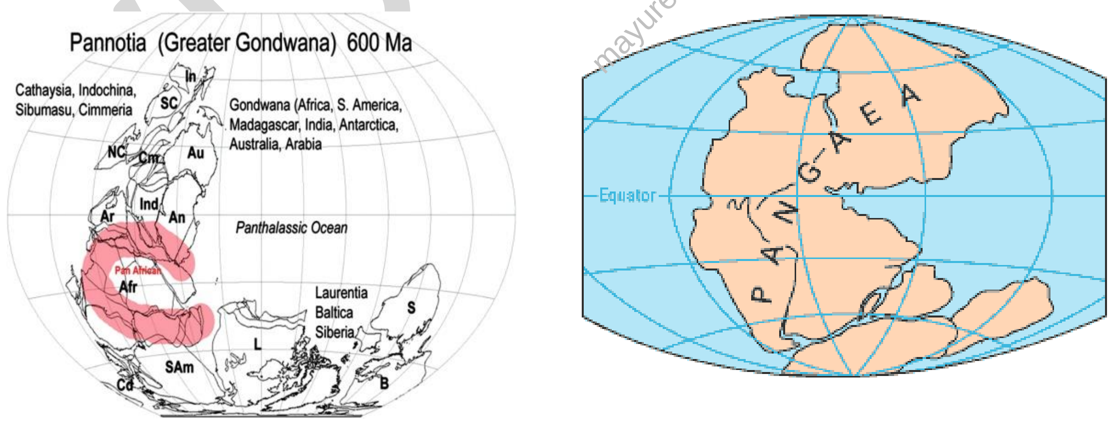
In the past, there existed many supercontinents at different time. The positions of continents have been accurately determined back to the early Jurassic period. However, beyond 200 million years, continental positions are much less certain. Following is the list of supercontinents.

Supercontinent name	Age
Ur (Vaalbara)	~3.6-2.8 Billion years ago
Kenorland	~2.7-2.1 Billion years ago
Proto Pangaea-Paleopangaea	~2.7-0.6 Billion years ago
Columbia	~1.8-1.5 Billion years ago
Rodinia	~1.25-0.75 Billion years ago
Pannotia	~600 Million years ago
Pangaea	~300 Million years ago

Table 1 – Supercontinents through geologic history

1.1. Supercontinent Cycle

Supercontinent does not last forever. A supercontinent cycle is the breakup of one supercontinent and the development of another. Pangaea , last supercontinent, was formed by the continental fragments dispersed during the breakup of Pannotia during the latter half of the Paleozoic Era (figure 1).



(a) Pannotia split **(b) Assembled Pangaea 200 million years ago**

Figure 1 - Supercontinents

Student Notes:

1.2. Pangaea

Like its predecessor Pannotia, the giant continent of Pangaea also became victim to the Earth's internal heat. According to Alfred Wegener, Pangaea which was surrounded on all sides by extensive water mass called **Panthalasa**, began to split around 200 million years ago. Pangaea broke into two large continental masses **Laurasia** and **Gondwanaland** forming the northern and southern components respectively. Subsequently, Laurasia and Gondwanaland continued to break into various smaller continents that exist today.

2. Continental Drift

Abraham Ortelius, a Dutch map maker, was the first one to propose the possibility of the two Americas, Europe and Africa to be once joined together as early as 1596. Antonio Snider drew a map showing the three continents together in 1858, but this was so much opposed to the scientific view then prevailing that nobody took notice of it. In 1910, F.B. Taylor of America invoked the hypothesis of horizontal displacement of continents or continental drift with a view to explaining the distribution of mountain ranges.

2.1. Continental Drift Theory of Alfred Wegener

It was Alfred Wegener – a German meteorologist - who put forth a comprehensive argument in the form of "the continental drift theory" in 1912. Wegener was a climatologist who wanted to explain the change of climates in the geological past. There are several geological evidences to show that there have been important and large scale changes in the climates of the world in the geological past. He came to the conclusion that either the climatic zones have moved or if they have not, then there has been movement of the landmasses. The distribution of Climatic belts of the world is governed primarily by the Sun. It, therefore, appear to be more probable that the landmasses have changed their position.

According to Wegener, all the continents formed a single continental mass, a mega ocean surrounded by the same. The super continent was named **PANGAEA**, a Greek word which meant all earth. The mega-ocean was called **PANTHALASSA**, meaning all water as shown in figure 1a. Wegner also imagined that in the carboniferous period the South pole was near the South African coast and the north pole lay in the Pacific ocean.

Wegener argued that, around 200 million years ago, the Pangaea began to split. The initial two blocks – Gondwanaland and Laurasia – started drifting away and in between a shallow sea emerged by filling up the water from Panthalasa. It was known as Tethys Sea. The present shape and relative position of the continents is the result of fragmentation of Pangaea by rifting and the drifting apart of the broken parts (figure 2). He called this drifting away of continents as Polflucht or the flight from the poles. He took help of theory of Isostasy in which the continental blocks, made of SIAL, are floating over the ocean floor, made of SIMA.

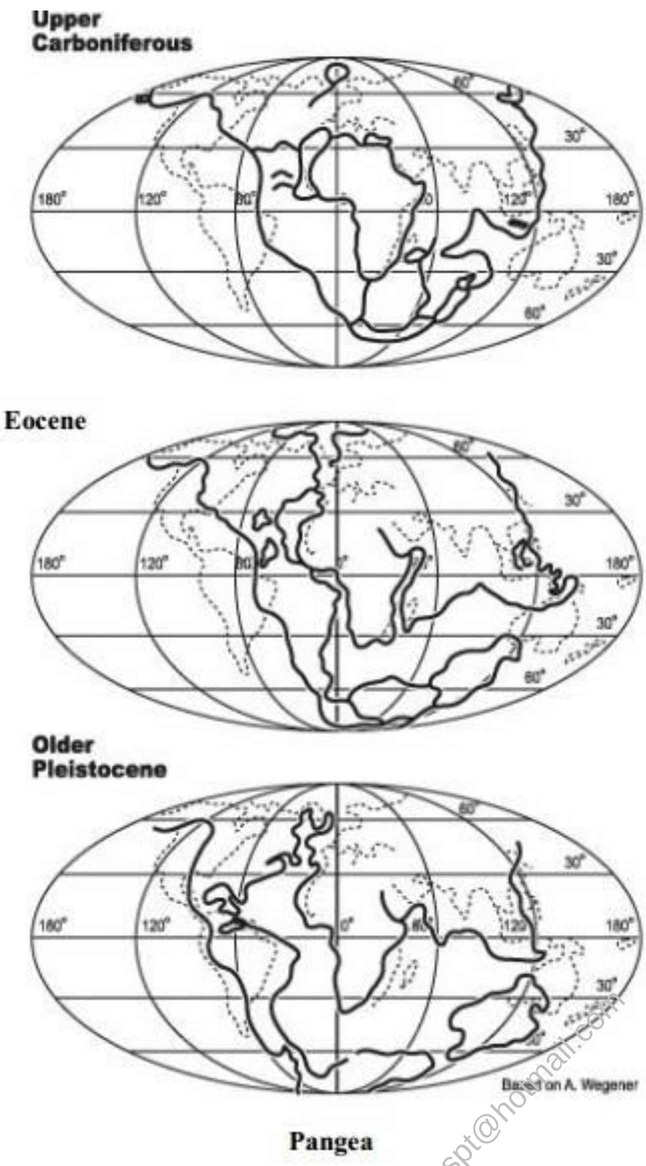


Figure 2 – Pangaea

2.1.1. Evidences in Support of the Theory

A variety of evidences were offered in support of the continental drift theory. These are summarized as:

- **(a)** The matching of continents ("jig-Saw-fit") – The shorelines of Africa and South America facing each other have a remarkable and unmistakable match. It may be noted that map produced using a computer programme to find the best fit of the Atlantic margin was presented by Bullard in 1964. It proved to be quite perfect. The match was tried at 1,000 fathom line instead of the present shoreline.
- **(b)** Rocks of Same Age Across the Oceans - The belt of ancient rocks of 2,000 million years from Brazil coast matches with those from western Africa. The earliest marine deposits along the coastline of South America and Africa are of the Jurassic age. This suggests that the ocean did not exist prior to that time. Similarly, Appalachian mountains of North America which come right up to the coast and then continue their trend across the North Atlantic Ocean in the old Hercynian fold mountains of South-West Ireland, Wales and Central Europe.

Student Notes:

(c) Tillite - It is the sedimentary rock formed out of deposits of glaciers. The Gondawana system of sediments from India is known to have its counter parts in six different landmasses of the Southern Hemisphere. At the base the system has thick tillite indicating extensive and prolonged glaciation. Counter parts of this succession are found in Africa, Falkland Island, Madagascar, Antarctica and Australia besides India. It clearly demonstrates that these landmasses had remarkably similar histories.

(d) Placer Deposits - The occurrence of rich placer deposits of gold in the Ghana coast and the absolute absence of source rock in the region is an amazing fact. The gold bearing veins are in Brazil and it is obvious that the gold deposits of the Ghana are derived from the Brazil plateau when the two continents lay side by side.

(e) Distribution of Fossils - The observations that **Lemurs** occur in India, Madagascar and Africa led some to consider a contiguous landmass "Lemuria" linking these three landmasses. **Mesosaurus** was a small reptile adapted to shallow brackish water. The skeletons of these are found only in two localities: the Southern Cape province of South Africa and Iraver formations of Brazil. The two localities presently are 4,800 km apart with an ocean in between them. Such presence of identical plants and animals is possible only when they lived on a common landmass.

2.1.2. Forces for Drifting

Wegener suggested that the movement responsible for the drifting of the continents was caused by pole-fleeing force and tidal force. The polar-fleeing force relates to the rotation of the earth. This was, according to Wegener, the cause for movement of continents towards equator ward. Tidal force – due to the attraction of the Moon and the Sun – was the main reason given by Wegener for the westward movement of the Americas. Wegener believed that these forces would become effective when applied over many million years.

2.1.3. Criticism of Wegener's Theory

It is clear that Wegener had amassed an imposing array of evidences in support of his theory and some of this evidence was undeniably convincing. But so much of theory was based on speculation and inadequate evidence that it provoked a lot of criticism and controversy.

(a) The greatest criticism has been the force of continental drift proposed by him. Tidal force need to be ten thousand million times stronger than at present to move the continents.

(b) Wegener proposed that Rockies and Andies mountain chain are formed during the westward drift of Americas. But if the SIAL (continents) is floating over SIMA (ocean floor), then the SIMA could not offer so much resistance as to cause folds and build mountain system.

(c) The jig-saw-fit of the opposing coasts of Atlantic Ocean was not so complete.

(d) Though there was similarity in the structural and stratigraphical features of the two coasts of the Atlantic, it would not be quite correct to conclude that one was an extension of the other and that they were joined together.

3. Post-Drift Studies

A number of discoveries during the post-war period added new information to geological literature. Most of the evidences for the continental drift theory of Alfred Wegener were collected from the continental areas. New literature collected from the ocean floor mapping provided new dimensions for the study of distribution of oceans and continents.

Student Notes:

3.1. Convection Current Theory

While explaining the processes of mountain building, Arthur Holmes put forward his theory of convection current in 1928-29. According to Holmes, convection currents exist in the mantle portion of

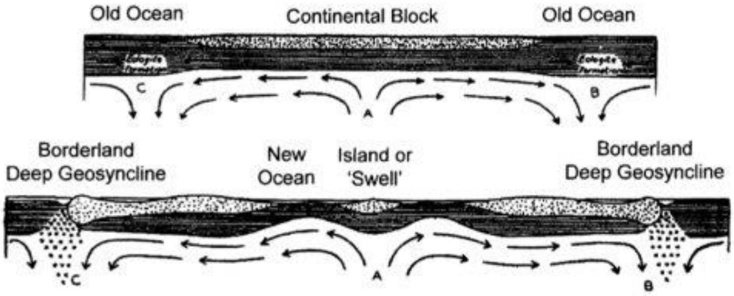


Figure 3 – Convection currents in the mantle portion of the Earth

the Earth as shown in figure 3. The cause of the origin of these currents is the presence of radioactive elements which causes thermal differences in the mantle portion. Holmes argued that there exists a system of such currents in the entire mantle portion. This was an attempt to provide an explanation to the issue of force, on the basis of which contemporary scientists discarded the continental drift theory.

3.2. Mapping of Ocean Floor

Post-war period saw surge in the detailed research of the ocean configuration. It revealed that ocean floor is not just a vast plain but is full of features such as mid-oceanic ridge, trenches, Abyssal plains etc. The mid-oceanic ridges were found to be most active in terms of volcanic eruptions. The age of rocks from Oceanic floor is nowhere more than 200 million years as compared to billions of year sold rocks from continental region and hence, oceanic rocks are much younger than the continental areas. Another interesting fact was that the rocks located equi-distant from the crest were found to have remarkable similarities in terms of their constituents, age, magnetic properties etc.

3.3. Sea Floor Spreading

The hypothesis of sea-floor spreading was first put forward by Harry Hess in 1961. Post-drift studies had been able to establish the facts which were not available at the time of Wegener. These may be summarized as:

- **(a)** The ocean crust rocks are much younger than the continental rocks. The age of rocks in the oceanic crust is nowhere more than 200 million years old compare to continental rocks out of which some are as old as 3,200 million years.
- **(b)** The sediments on the ocean floor are unexpectedly very thin and thickness of the sediments increases with the distance from the ridge. They were only 6 to 7 km thick, whereas below the continental surfaces this thickness was 30 to 40 kms.
- **(c)** Mid-oceanic ridge was not found only in Atlantic Ocean, but ridges were present in all the oceans. These ridges contain large scale evidences of faulting and volcanicity and are bringing huge amounts of lava to the surface.
- **(d)** The rocks equidistant on either sides of the crest of mid-oceanic ridges show remarkable similarities in terms of period of formation, chemical compositions and magnetic properties. Rocks closer to the mid-oceanic ridges are of normal polarity and are the youngest. The age of the rocks increases as one moves away from the crest.

Student Notes:

On the basis of above facts the realization dawned that the ocean floor possibly is the youngest and most active part of the earth's surface. In 1961, Harry Hess argued that the ocean floor was mobile and

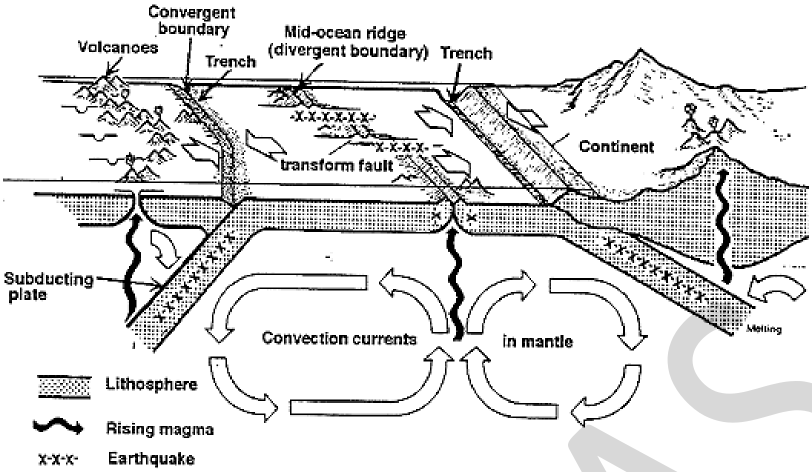


Figure 4 – Sea-floor spreading

constant eruption at the crest of oceanic ridges causes the rupture of the oceanic crust and the new lava wedges into it, pushing the oceanic crust on either side as shown in figure 4. The ocean floor, thus spreads. But this spreading does not cause the shrinking of the other. Hess argued about the sinking of the crust which was spread in the trench system and does it gets consumed. On analysis, it was found that 2 cm/year is adequate for separation of South America from Africa in about 200 million years.

4. Plate Tectonics

Since the advent of the concept of sea floor spreading, the interest in the problem of distribution of oceans and continents was revived. The hypothesis of plate tectonics is an extended and more comprehensive version of the theory of sea-floor spreading. This is a great unifying concept which "draws sea-floor spreading, continental drift, crustal structures and world pattern of seismic and volcanic activity together as aspects of one coherent picture."

The term plate was first used by Tuzo Wilson in his definition of transform faults in 1965, but the hypothesis of plate tectonics was first outlined by W.J. Morgan in 1967. More or less concurrently but independently D.P. Mackenzie and Parker had arrived at similar conclusions. It first came to be known by the name of New Global Tectonics but after sometime the term Plate Tectonics gained currency. Basic assumptions of plate tectonics are as follows:

1. There is spreading of sea floor and new oceanic crust is being continually created at the active mid-oceanic ridges and destroyed at trenches.
2. The area of the earth's surface is fixed. It means, the amount of crust consumed almost equals the amount of new crust created.
3. The new crust that is formed becomes part and parcel of a plate.

4.1. Major and Minor Plates

A tectonic plate (also called lithospheric plate) is a massive, irregularly-shaped slab of solid rock. Plates are generally composed of both continental and oceanic lithosphere. This is an important difference between plate tectonics and continental drift theories. The lithosphere includes the crust and the top mantle with its thickness range varying between 5-100 km in oceanic parts and about 200 km in the continental areas. The plates are the inert aseismic regions bounded by narrow mobile belts which are characterized by Seismic and volcanic activity or by orogenic belts. Plates' configuration is not related to the distribution of land and water. Plates can split or get welded with adjoining plate.

The theory of plate tectonics proposes that the earth's lithosphere is divided into seven major and some minor plates. The major plates are as follows:

- **(a)** Antarctic plate - Antarctica and the surrounding ocean
- **(b)** North American plate – North America continent along with Western Atlantic floor separated from the South American plate along the Caribbean islands
- **(c)** South American plate – South America continent along with western Atlantic floor
- **(d)** Pacific plate – covers almost entire pacific ocean
- **(e)** India-Australia-New Zealand plate – Australian continent along with Indian sub-continent and Indian Ocean.
- **(f)** African plate – Africa continent along with eastern Atlantic floor
- **(g)** Eurasian plate – Eurasia along with eastern Atlantic floor

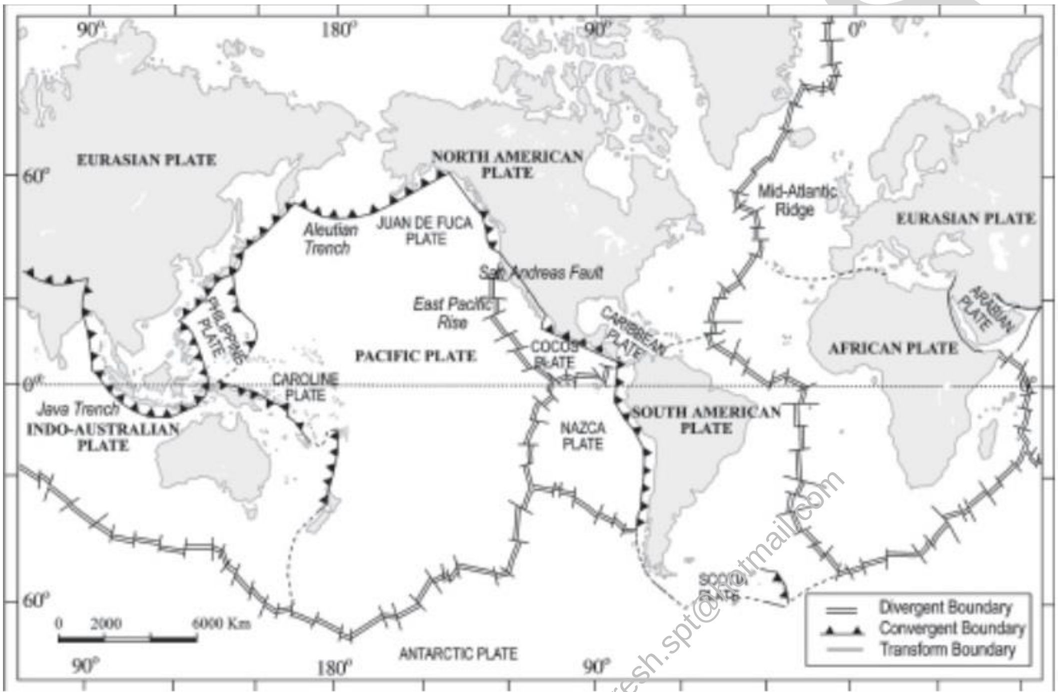


Figure 5 – Major and Minor plates of the world

Minor plates are small in areas. They are also moving in different directions like major plates. Some important minor plates are listed below:

- **(a)** Cocos plate – Between Central America and Pacific plate
- **(b)** Nazca plate – Between South America and Pacific plate
- **(c)** Arabian plate – Mostly the Saudi Arabian landmass
- **(d)** Philippine plate – Between the Asiatic and Pacific plate
- **(e)** Caroline plate – Between the Philippine and Indian plate (North of New Guinea)
- **(f)** Fuji plate– North-east of Australia.

4.2. Movement of Plates

These tectonic plates float on and travel independently over the asthenosphere, which lies over the mantle. Much of the earth's seismic activities occur at the boundaries of these plates. It is a relatively slow movement, driven by thermal convection currents and other geological activities originating deep within the earth's mantle. Plates have moved horizontally over the asthenosphere as rigid units.

The movement of a plate is defined by the position of its pole of rotation and its angle of rotation about the rotation axis; its rate of movement varying with distance from the pole of rotation, being nil at the pole and reaching a maximum at the equator relative to the pole of rotation. The strips of normal and reverse magnetic field that parallel the mid-oceanic ridges help scientists determine the rates of plate movement. These rates vary considerably.

The arctic ridge has the slowest rate(less than 2 cm per year), and the East Pacific Rise near Easter Island in the South Pacific has the fastest rate (more than 15 cm per year). The eastern part (Australia) is moving northward at the rate of 5.6 cm per year while the western part (India) is moving only at the rate of 3.7 cm per year due to impediment by Himalayas. This differential movement is resulting in the compression of the plate near its center at Sumatra and a potential division into Indian and Australian Plates. The rate of spreading at the Mid-Atlantic Ridge near Iceland is relatively slow, about 2 cm per year.

4.2.1. Movement of The Indian Plate

The Indian plate includes Peninsular India and the Australian continental portions. India was a large island situated off the Australian coast, in a vast ocean. The Tethys sea separated it from the Asian

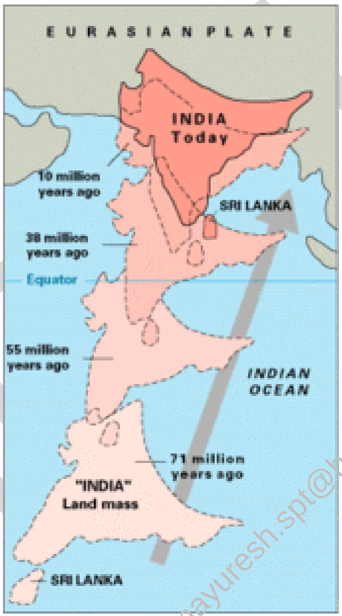


Figure 6 – Movement of the Indian Plate

continent. India is believed to have started her northward journey about 200 million years ago. India collided with Asia about 40-50 million years ago causing formation of Himalayas. The subduction zone along the Himalayas forms the northern plate boundary in the form of continent— continent convergence. Scientists believe that the process is still continuing and the height of the Himalayas is rising even to this date.

4.3. Types of Boundaries

Plate boundaries are very important and significant structural features. Nearly all seismic, volcanic and tectonic activities are confined to the plate margins. Boundaries are very distinct and easy to identify. They are associated with newly formed mountain systems, oceanic ridges and trenches. Plates are moving continuously and have relative direction of movement. Based on the direction of movement three types of plate boundaries can, easily, be identified (figure 7).

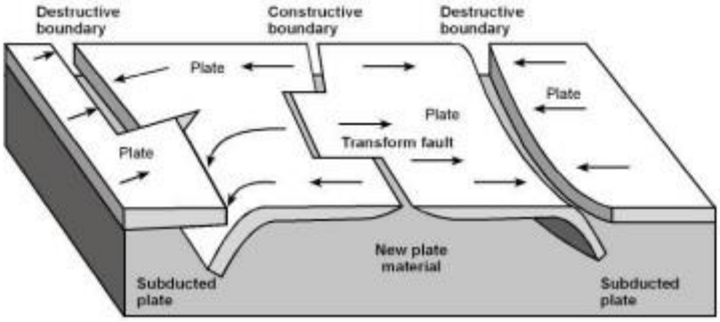


Figure 7 – Types of plate boundaries

4.3.1. Divergent Boundaries

Where new crust is generated as the plates pull away from each other. The sites where the plates move away from each other are called spreading sites. The best-known example of divergent boundaries is the Mid-Atlantic Ridge. At this, the American Plate(s) is/are separated from the Eurasian and African Plates at rate of around 2 cm per year.

4.3.2. Convergent Boundaries

Where the crust is destroyed as one plate dived under another at an angle of approximately 45^0. The location, where sinking of a plate occurs, is called a subduction zone. There are three ways in which convergence can occur. These are: (i) between an oceanic and continental plate; (ii) between two oceanic plates; and (iii) between two continental plates.

4.3.3. Transform Boundaries

Where the crust is neither produced nor destroyed as the plates slide horizontally past each other. Transform faults are the planes of separation generally perpendicular to the mid-oceanic ridges. As the eruptions do not take all along the entire crest at the same time, there is a differential movement of a portion of the plate away from the axis of the earth. Also, the rotation of the earth has its effect on the separated blocks of the plate portions.

4.4. Forces for the Plate Movement

At the time of Wegener, it was believed that the earth was a solid, motionless body. However, sea floor spreading and tectonic plate theories emphasized that both the surface of the earth and the interior are dynamic. Generally, it is accepted that tectonic plates are able to move because of the relative density of oceanic lithosphere and the relative weakness of the asthenosphere. The convection currents (proposed by Arthur Holmes) get diverted or converged on approaching the crust layer. Heat within the earth comes from two main sources: radioactive decay and residual heat.

4.5. Objections to Plate Tectonics Theory

Although plate tectonics has been a powerful principle to explain distribution of continents and oceans, there are several problems to which it has not been able to offer a satisfactory solution.

- **(a)** The length of the spreading ridge is far greater than the subduction zone.
- **(b)** Plate tectonics is unable to explain why subduction is limited to the Pacific coasts while spreading is found in all the Oceans.
- **(c)** It has failed to provide a satisfactory explanation for mountain building. Mountain ranges such as eastern highlands of Australia etc which cannot be related to plate tectonics.

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(d) It is not definite that each plate behaves like a unit, and some people have proposed an increase in the number of plates.

5. Endogenic and Exogenic Forces

The earth's crust is dynamic which has moved and moves vertically and horizontally. It is being continuously subjected to external forces induced basically by sunlight as well as by internal forces caused by events occurring inside the earth. The external forces are known as exogenic forces and the internal forces are known as endogenic forces. The variations in the relief over the earth surface remain as long as the opposing actions of exogenic and endogenic forces continue. The net resultant of these forces shape the landforms across the earth's surface. We can divide landforms into two basic categories – initial landforms and sequential. The initial landforms are produced by endogenic forces. These initial landforms are modified and shaped by the exogenic forces with simultaneous application of endogenic forces.

5.1. Geomorphic Processes and Agents

Geomorphology is the study of nature and origin of landforms. One of the approaches for such study is deductive reasoning which depended largely on the geomorphic processes. The endogenic and exogenic forces causing physical stresses and chemical actions on earth materials and bringing about changes in the configuration of the surface of the earth are known as geomorphic processes. The action of exogenic forces result in wearing down (degradation) of relief and filling up (aggradation) of basins, on the surface of the earth. On the other hand, the endogenic forces continuously elevate or build up parts of the earth's surface.

On the other hand, geomorphic agent is any exogenic element of nature like wind, waves, water, ice, ocean currents, etc. capable of acquiring and transporting earth material. When these elements of nature become mobile due to gradients, they remove the materials and transport them over slopes and deposit them at lower level.

A process is a force applied on the earth material affecting the same. An agent is a mobile medium which removes, transports and deposits earth materials. Unless stated separately, geomorphic processes especially exogenic and geomorphic agents are one and the same.

5.2. Endogenic Processes

The energy emanating from within the earth is the main force behind endogenic geomorphic processes. This energy is mostly generated by radioactivity, rotational and tidal friction and primordial heat from the origin of the earth. This energy due to geothermal gradients and heat flow from within induces diastrophism and volcanism in the lithosphere. Due to variations in geothermal gradients and heat flow from within, crustal thickness and strength, the action of endogenic forces are not uniform and hence the tectonically controlled original crustal surface is uneven. Diastrophism and Volcanism are included in endogenic geomorphic processes. These may be summarized as:

5.2.1. Diastrophism

All processes that move, elevate or build up portions of the earth's crust come under diastrophism. These forces operate **slowly** and their effects are visible only after thousands of years. The diastrophic forces include both the vertical and horizontal movements. They include:

(a) Orogenic processes involve mountain building through severe folding, faulting, thrusting, often as a result of plate tectonics. It includes forces of compression and tension which are tangential to the earth's surface in contrast to radial forces under epeirogenesis. Under compression forces, sediments within geosynclines are buckled and deformed into long, linear mountain chains (Himalayas). Under the operation of intense tensional forces, the rock strata are fractured. The line along which displacement of the fractured rock strata takes place is called the fault line (Narmada rift valley).

(b) **Epeirogenic processes** involve upliftment or depression of the Earth's crust at a continental scale which moves the crustal rocks enmasse in a vertical or radial direction. It is a continental building process. Epeirogenic movement can be permanent or transient. The movement is caused by a set of forces acting along the Earth radius, such as those contributing to isostasy and faulting. For ex - Epeirogenic movement has caused the southern Rocky Mountain region to be uplifted from 1300 to 2000m in the past.

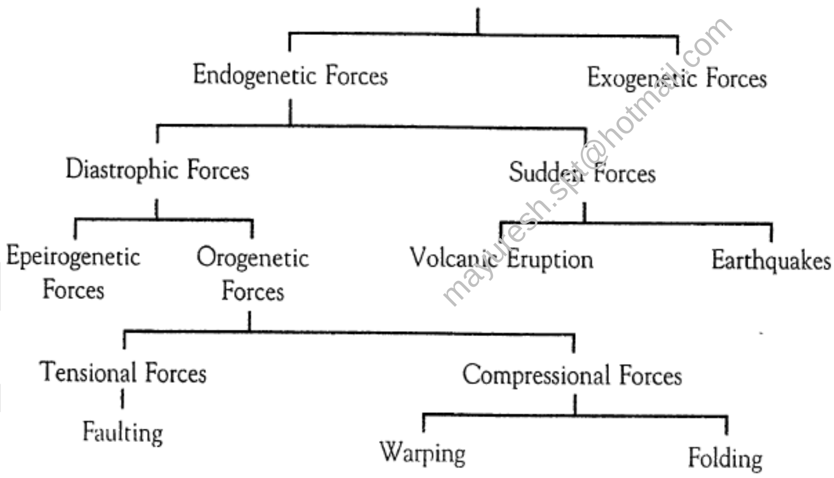
(c) **Earthquake**[1] involves a shock or series of shocks due to sudden movement of crustal rocks within the crust or mantle. Earthquakes are generally associated with boundaries of tectonic plates. There are instances where earthquakes have occurred well inside the tectonic plate. The release of energy occurs along the fault. A fault is a sharp break in the crustal rocks. Tendency of rocks to move apart at some point of time overcomes the friction. This causes release of energy and the energy waves in all directions.

(d) **Plate tectonics** involves horizontal movements of crustal plates.

5.2.2. Volcanism

Volcanism includes the movement of molten rock (magma) onto or toward the earth's surface and also formation of many intrusive and extrusive volcanic forms. The layer below the solid crust is mantle which contains a weaker zone called asthenosphere. It is from this that the molten rock material finds their way to the surface. The material in the upper mantle portion is called magma. The magma is conveyed to the surface essentially along tube-like conduits and the extrusion of lava builds distinctive conical or dome shaped landforms.

FORCES WHICH AFFECT THE EARTH'S CRUST



5.3. Exogenic Processes

The exogenic processes derive their energy from atmosphere determined by the ultimate energy from the sun and also the gradients created by tectonic factors. They are essentially processes of land destruction.

[1] earthquakes involving local relatively minor movements.

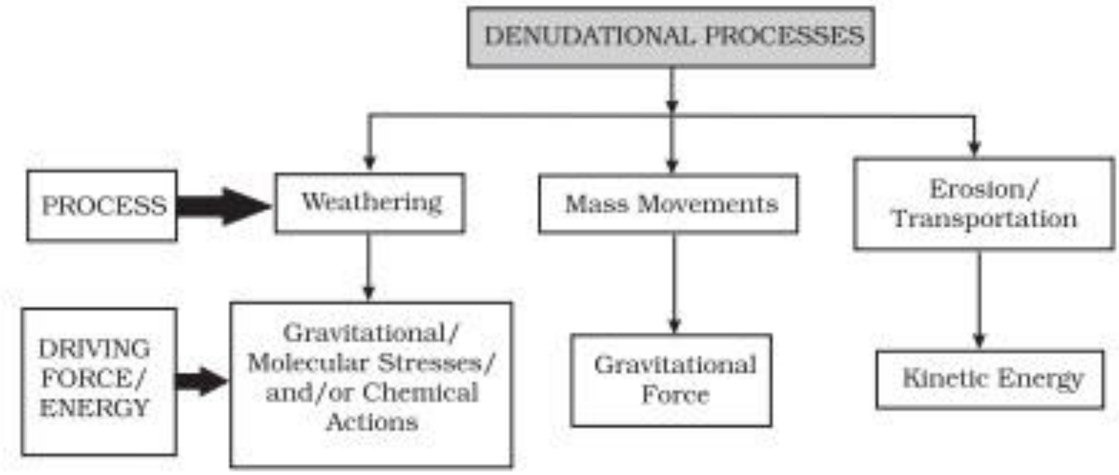


Figure 8 – Denudational process and their driving forces

The basic reason of these processes is development of stresses in the body of the earth materials. It is this stress that breaks rocks and other earth materials. The shear stresses result in angular displacement or slippage. Stress can be produced by gravitation pull, climatic factors – thermal gradients, pressure gradients, amount and intensity of precipitation, humidity etc. The density, type and distribution of vegetation also exert influence on exogenic processes. The exogenic geomorphic processes vary from one climatic region to another. These vary within a climatic region also due to location variation in climatic elements.

All the exogenic geomorphic processes are covered under a general term, called denudation which means to strip off. Denudation consists of two kinds of processes – static and mobile. Weathering is a static process while mass movement, erosion and transportation are mobile processes (figure 8).

5.3.1. Weathering

Weathering may be described as the mechanical disintegration or chemical decomposition of rocks in situ by different geomorphic agents at or near the surface of the earth. It changes hard massive rock into finer material. It is the first phase in the denudation process which prepares rock materials for transportation by the agents of erosion and mass movement.

The main factors responsible for weathering are geological – rock structure, climatic, topographic and vegetative. These factors result into activities such as thermal expansion, exfoliation, rock solutions, salt and ice crystallization etc. There are three types of weathering which are described below in detail.

I. Chemical Weathering Process

No rock-forming mineral is absolutely chemically inert; some are more readily altered than others. A variety of chemical actions such as carbonation, hydration, oxidation and reduction act on the rocks to decompose and dissolve them. Water, air (Oxygen and carbon dioxide) along with heat must be present to speed up all chemical reactions. Biological activities such as decomposition of plants and animals increase acidity and other elements in the crust which enhances chemical weathering.

- **Hydration:** is a process by which certain types of mineral expand as they take up water and expand, causing additional stresses in the rock due to increase in the volume of mineral itself. For instance, calcium sulphate absorbs water and turns to gypsum. Decomposed products of rock-forming minerals are also subjected to hydration, thereby accelerating the disintegration of the rock. This process of hydration is reversible and continued repetition

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causes fatigue in the rock which eventually may lead to cracking of overlaying materials and finally disintegration.

- **Oxidation and reduction:** oxidation is the addition of oxygen to form oxides or hydroxides while reduction is the reverse of oxidation. Oxidation occurs when mineral has access to atmosphere or oxygenated water. To put it simply, they rust. Red color of iron turns to brown upon oxidation.
- **Solution:** few minerals such as rock salt are significantly soluble in water. Such rock-forming minerals are easily leached out without leaving any residue in rainy climates and accumulate in dry regions. Minerals like calcium carbonate present in limestones are soluble in water containing carbonic acid. Carbon dioxide produced by decaying organic matter along with soil water greatly aids in this reaction.
- **Carbonation:** many minerals are soluble in rainwater, which contains carbon dioxide and acts as a weak carbonic acid. This is particularly important in the decomposition of limestones; the rain water converts the calcium carbonate into calcium bicarbonate, which is soluble and can be taken away in the groundwater.

These weathering process are inter-related. Hydration, oxidation, carbonation etc. go hand-in-hand and hasten the weathering process.

II. Physical Weathering Process

Physical weathering is the mechanical disintegration of rock-forming minerals by different geomorphic agents. The main factors responsible for it are (i) temperature change, (ii) the crystallization of water or other crystal growth, (iii) pressure-release mechanism, (iv) mechanical action of plants and animals. These factors act slow but can cause great damage to the rocks because of continued stress or fatigue developed in the rock.

- <u>Expansion by unloading</u> – pressure release (unloading) mechanism causes disintegration of rock. It is because of continued erosion by various geomorphic agents. Fractures develop roughly parallel to the surface. This process has been termed exfoliation. Exfoliated sheets may measure thousands of meters.
- <u>Temperature change and expansion</u> – thermal expansion of rock is the cause of rock cracking and disintegration. If you travel to arid-tropics, it is possible that you may hear sounds like rifle shots which are actually cracking of the rock as they contract. The theory is that rocks are poor conductors of heat. Due to strong diurnal heating, the outer layers of the rock warm up considerably, but do not transmit heat to the inner layers. During night when temperature falls, same layer gets contracted. This should lead to the setting up of stresses in the rock, causing fracturing parallel to the surface
- <u>Salt weathering</u> – a number of salts such as Sodium Chloride, Calcium sulphate may enter rocks in dissolved form. On drying and crystallization they expand and set up a disruptive effect. Expansion of these salts depends on temperature and their own thermal properties. Force exerted by crystallization is sometimes more than the tensile strength off rocks, thus causes splitting. Areas with alternating wetting and drying conditions favour salt weathering.
- <u>Frost action and crystal growth</u> – frost action is one of the most important weathering processes in cold climates. When water fills the pores, cracks and crevices in rocks and then freezes, it expands and exerts a bursting pressure. The rocks are fractured, cracked. In this process, rate of freezing is important. Freezing also penetrates to a greater depth when the ground is bare rather than forest covered.

These processes – chemical and mechanical – are not stand alone activities. Different processes acted upon same rock and produced net resultant weathered material together. For instance, both chemical and mechanical weathering processes further weaken the joints, the layers

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thereby peeling off in sheets. It is probably best to conclude that chemical weathering and pressure release ally with temperature changes to produce rock disintegration. It is likely that hydration process may also be involved when crystallization takes place. Another instance is of hydration where hydration itself is a mechanical effect, but it occurs intimately with hydrolysis in such a manner that it is difficult to draw any hard and fast line here between mechanical and chemical weathering. Actions of plants, human and animal affect both chemical and mechanical weathering.

III. Biological Activity

It includes the role of plants and animal in promotion of both physical and chemical weathering. Burrowing and wedging by organisms like earthworms, termites, rodents etc., help in exposing the new surfaces to chemical attack and assist in the penetration of moisture and air. Human beings by disturbing vegetation, ploughing and cultivating soils, also help in mixing and creating new contacts between air, water and minerals in the earth materials. Tree roots can occasionally be shown to have forced apart adjacent blocks of rock. Decaying plant and animal matter help in the production of humic, carbonic and other acids which enhance decay and solubility of some elements.

5.3.2. Mass Movement

Mass movement or mass wasting is the term used for the movement of material down a slope under the influence of gravity. Thus it excludes those in which material is carried directly by a transporting medium such as running water, wind or ice. That means mass movement does not come under erosion though there is a shift of materials from one place to another. The movement of mass may range from slow to rapid, affecting shallow to deep columns of materials and include creep, flow, slide and fall. Weathering is not a pre-requisite for mass movement though it aids mass movement.

Mass wasting is viewed as a transitional phenomenon between weathering which is defined as occurring in situ and erosion which requires as one element transport by some agent. Mass wasting combines elements of both weathering and erosion.

Factors favouring mass movement are: (i) weathering; (ii) rock composition; (iii) texture and structure of material; (iv) slope gradient; (v) extent of lubrication. Several activities precede mass movements. They are : (i) removal of support from below to materials above through natural or artificial means; (ii) increase in gradient and height of slopes; (iii) overloading through addition of materials naturally or by artificial filling; (iv) overloading due to heavy rainfall, saturation and lubrication of slope materials; (v) removal of material or load from over the original slope surfaces; (vi) occurrence of earthquakes, explosions or machinery; (vii) excessive natural seepage; (viii) heavy drawdown of water from lakes, reservoirs and rivers leading to slow outflow of water from under the slopes or river banks; (ix) indiscriminate removal of natural vegetation.

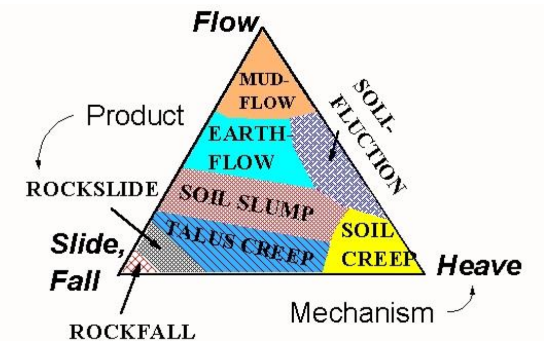

Figure 9 - Relationships among different types of mass movements

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Heave (heaving up of soils due to frost growth and other causes), flow and slide are the three types of mass movements (figure 9). Mass movements can be grouped under three major classes:

- Slow movements – the slow downhill movement of debris and soil on moderate slope is described as **creep**. Depending upon the type of material involved, several types of creep viz., soil creep, talus creep, rock creep, rock-glacier creep etc., can be identified. Leaning fence post, accumulation of earth on the upslope side of stone walls, etc. are example of creep. Also included in this group is **solifluction** which involves slow downslope flowing soil mass or fine grained rock debris saturated or lubricated with water. This process is quite common in moist temperate areas where surface melting of deeply frozen ground and long continued rain respectively, occur frequently. The permanently frozen ground prevents the downward percolation of water in summer, producing a highly saturated and mobile soil layer. Also, there is absence of deep-rooted vegetation to bind the soil. Solifluction can occur on slopes of 3^0 or less.
- Rapid movement – these depend on there being sufficient water to saturate comprehensively the soil mass. These movements are mostly prevalent in humid climatic regions and occur over gentle to steep slopes. **Earthflow** is movement of water-saturated clayey or silty earth materials down hillsides. When slopes are steeper, even the bedrock especially of soft sedimentary rocks like shale or deeply weathered igneous rock may slide downslope. Another type in this category is **mudflow**. In the absence of vegetation cover and with heavy rainfall, thick layers of weathered materials get saturated with water and either slowly or rapidly flows down along definite channels. It looks like a stream of mud within a valley. Mudflows occur frequently on the slopes of erupting or recently erupted volcanoes. A third type is the debris **avalanche**, which is more characteristic of humid regions. Avalanche can be much faster than the mudflow.
- Landslides – In these, as the velocity does not continually decrease downwards, there must be one or more shear surfaces on which movement takes place. Where the shear surface is approximately planar, the strict meaning of the term slide is appropriate. However, another common type of landslide takes place on arcuate shear planes, and these are called rotational slips. It results into slumping of debris with backward rotation. Most landslides usually occur fairly rapidly, often after excess groundwater following heavy rain has reduced soil strength. Over steep slopes, rock sliding is very fast and destructive.

5.3.3. Erosion and Deposition

The erosion can be defined as "application of the kinetic energy associated with the agent to the surface of the land along which it moves". Erosion is a term referring to those processes of Denudation which wear away the land surface by the mechanical action of the debris which is being acquired and transported by various agents of erosion. The agents by themselves are also capable of erosion. Abrasion by rock debris carried by these geomorphic agents also aid greatly in erosion. For erosion to occur the agent must be capable of exerting a force on the surface greater than its shear strength.

When massive rocks break into smaller fragments through weathering and any other process, erosional geomorphic agents like running water, groundwater, glaciers, wind and waves remove and transport it to other places depending upon the dynamics of each of these agents. Weathering aids erosion but it is not a pre-condition for erosion to take place.

Deposition is a consequence of erosion. The erosional agents loose their velocity and hence energy on gentler slopes and the materials carried by them start to settle themselves. The coarser materials get deposited first and finer ones later. Alluvial fans at the foothills, alluvial plains, delta etc. are few examples of deposition landforms.

Student Notes:

UPSC Questions

1. What do you understand by the theory of continental drift? Discuss the prominent evidences in its support.(UPSC 2013/5 Marks)
2. Sea-floor spreading. (UPSC 2010/5 Marks).

Student Notes:

CONTINENT DRIFT, SEAFLOOR SPREADING, ENDOGENIC AND EXOGENIC FORCES AND BASICS OF PLATE TECTONICS, SOME IDEAS ABOUT SUPERCONTINENTS ETC.

Contents

1. Earthquakes

An earthquake in simple words is shaking of the earth. It is caused due to release of energy, which generates waves that travel in all directions.

The release of energy occurs along a fault. A fault is a sharp break in the crustal rocks. Rocks along a fault tend to move in opposite directions. As the overlying rock strata press them, the friction locks them together. However, their tendency to move apart at some point of time overcomes the friction. As a result, the blocks get deformed and eventually, they slide past one another abruptly. This causes dissipation of energy, and the energy waves travel in all directions.

The point where the energy is released is called the **focus** of an earthquake, alternatively, it is called the **hypocentre**. The energy waves travelling in different directions reach the surface. The point on the surface, nearest to the focus, is called **epicentre**. It is the first one to experience the waves. It is a point directly above the focus.

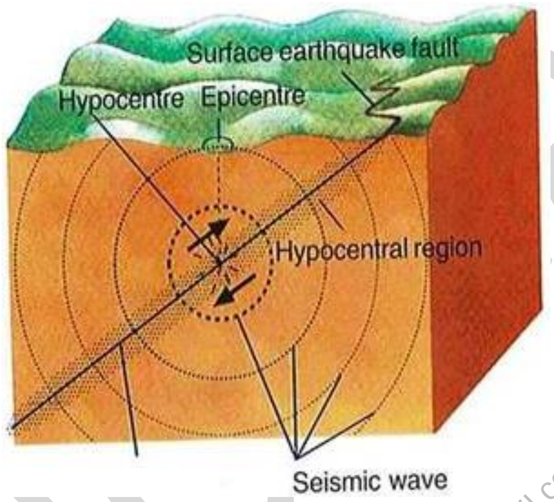

Figure 1: Hypocentre and Epicentre

1.1. Types of Earthquakes

1. **Tectonic Earthquakes**: These are generated due to sliding of rocks along a fault plane. This movement causes imbalance in the crustal rocks which results in earthquakes of varying magnitude, depending upon the nature of dislocation in the rock strata.
2. **Volcanic Earthquakes:** Volcanic activity is considered to be one of the main causes of earthquakes. In fact, volcanic activity and seismic events are so intimately related to each other that they become cause and effect for each other. Each volcanic eruption is followed by an earthquake and many of the severe earthquakes can cause volcanic eruptions.
   The explosive violent gases during the process of volcanic activity try to escape upward and hence they push the crustal surface from below with great force. This leads to severe tremors of high magnitude, which depend upon the intensity of volcanic eruptions.
3. **Collapse Earthquakes:** In areas of intense mining activity, sometimes the roofs of underground mines collapse causing minor tremors.
4. **Explosion Earthquakes:** Ground shaking may also occur due to the explosion of chemical or nuclear devices.
5. The earthquakes that occur in the areas of large reservoirs are referred to as **reservoir induced earthquakes**.
   Above may also be referred as various causes of earthquakes with one and two being the **natural causes** of earthquakes while three, four and five represent **anthropogenic** or **man-made** causes of earthquakes.

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1.2. Seismic Waves

The waves generated by an earthquake are called the 'seismic waves' or 'earthquake waves'. These are recorded by an instrument called the **seismograph** or the **seismometer**. For further understanding of earthquake waves, refer to the portion of the notes on 'Interior of Earth'.

1.3. Depth of Earthquakes

Earthquake focus depth is an important factor in shaping the characteristics of the waves and the damage they inflict. The focal depth can be **deep** (from 300 to 700 km), **intermediate** (60 to 300 km) or **shallow** (less than 60 km). Deep focus earthquakes are rarely destructive because the wave amplitude is greatly attenuated by the time it reaches the surface. Shallow focus earthquakes are more common and are extremely damaging because of their close proximity to the surface

1.4. Measurement of Earthquakes

The earthquake events are scaled either according to the magnitude or intensity of the shock.

1.4.1. Magnitude Scale

Magnitude is the amount of energy released and is based on the direct measurement of the size of seismic waves. The magnitude scale is known as the **Richter Scale**.

The **Richter magnitude scale** was developed in 1935 by Charles F. Richter as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the *logarithm of the amplitude* of waves recorded by seismographs. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a *ten fold increase* in measured amplitude; as an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy than the amount associated with the preceding whole number value.

1.4.2. Intensity Scale

Intensity of an earthquake is measured in terms of its effects on human life. The intensity of an earthquake at a specific location depends on a number of factors. Some of them are:

- the total amount of energy released,
- the distance from the epicentre,
- the types of rocks and the degree of consolidation.

The **Mercalli intensity scale** is a scale used for measuring the intensity of an earthquake. The scale quantifies the effects of an earthquake on the Earth's surface, humans, objects of nature, and man-made structures on a scale of **I** through **XII**, with I denoting 'not felt', and XII 'total destruction'. Data is gathered from individuals who have experienced the quake, and an intensity value will be given to their location.

Characteristic	Mercalli Scale	Richter Scale
Measures	The effects caused by earthquake	The energy released by the earthquake
Measuring Tool	Observation	Seismograph
Calculation	Quantified from observation of effect on earth's surface, human, objects and man-made structures	Base-10 logarithmic scale obtained by calculating logarithm of the amplitude of waves.

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Scale	I (not felt) to XII (total destruction)	From 2.0 to 10.0+ (never recorded). A 3.0 earthquake is 10 times stronger than a 2.0 earthquake.
Consistency	Varies depending on distance from epicentre.	Varies at different distances from the epicentre, but one value is given for the earthquake as a whole.

Table 1: Comparison between Richter and Mercalli Scale

1.4.3. Classification of Earthquakes

Category	Magnitude on Richter Scale
Slight	Upto 4.9
Moderate	5.0 to 6.9
Great	7.0 to 7.9
Very Great	8.0 and more

Table 2: classification of earthquakes based on magnitude

1.5. Distribution of Earthquakes

Most earthquakes in the world are associated with the following:

- the zones of young fold mountains,
- the zones of faulting and fracturing,
- the zones representing the junctions of continental and oceanic margins,
- the zones of active volcanoes, and
- along the different plate boundaries.

1.5.1. Seismic Belts of the world

The main seismic belts are as under:

1. **Circum-Pacific Belt:** The Belt includes the coastal margins of North America, South America and East Asia. These are as represent the eastern and western margins of the Pacific Ocean respectively, and account for about 65 per cent of the total earthquakes of the world.
   The **western marginal zones** are represented by the Rockies and the Andes mountain chains. These are also the zones of convergent plate boundaries where the Pacific oceanic plate is subducted below the American plates.
   The **eastern marginal zones** are represented by the island arcs of Kamchatka, Sakhalin, Japan and Philippines. The earthquakes are caused due to collision of the Pacific and the Asiatic plates and the consequent volcanic activity. Japan records about 1500 seismic shocks every year.
2. **Mid-Continental Belt:** The Mid-Continental Belt includes the Alpine mountains and their off shoots in Europe, Mediterranean Sea, northern Africa, eastern Africa and the Himalayas.
   The Mid-Continental Belt extends through Sulaiman and Kirthar zones in the west, the Himalayas in the north and Myanmar in the east. This belt represents the weaker zone of Fold Mountains. About 21 per cent of the total seismic events are recorded in this belt.
3. **Mid-Atlantic Ridge Belt:** The Mid-Atlantic Ridge Belt includes the Mid-Atlantic ridge and several islands near the ridge. It records moderate earthquakes which are caused due to the moving of plates in the opposite directions. Thus the seafloor spreading and the fissure type of volcanic eruptions cause earthquakes of moderate intensity in this region.

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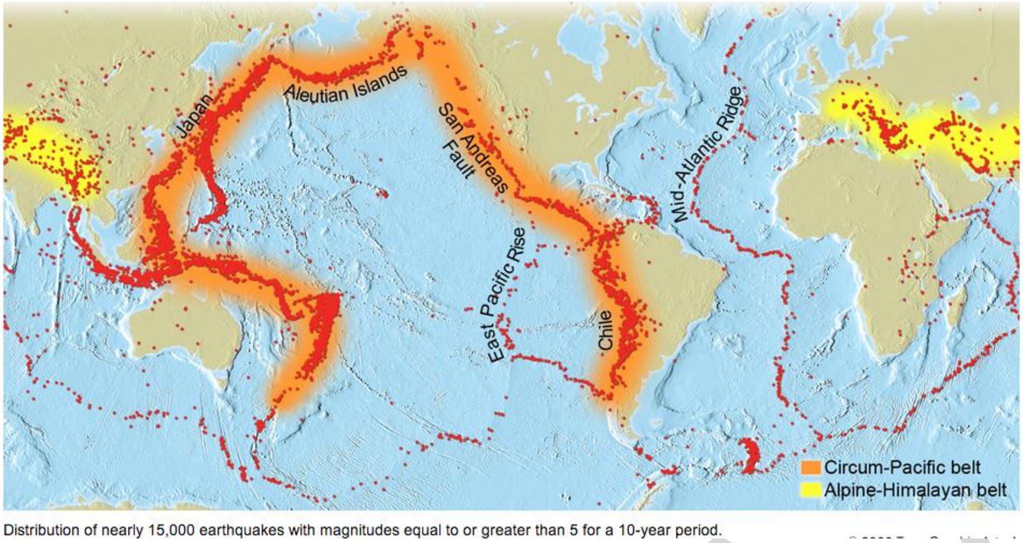

Figure 2: Distribution of Earthquake belts

1.5.2. Seismic Zones of India

The Indian sub-continent is highly prone to multiple natural disasters including earthquakes, which is one of the most destructive natural hazards with the potentiality of inflicting huge loss to lives and property. Earthquakes pose a real threat to India with 59% of its geographical area vulnerable to seismic disturbance of varying intensities including the capital city of the country.

The varying geology at different locations in the country implies that the likelihood of damaging earthquakes taking place at different locations is different. Thus, a seismic zone map is required so that buildings and other structures located in different regions can be designed to withstand different level of ground shaking. The current zone map divides India into four zones – II, III, IV and V.

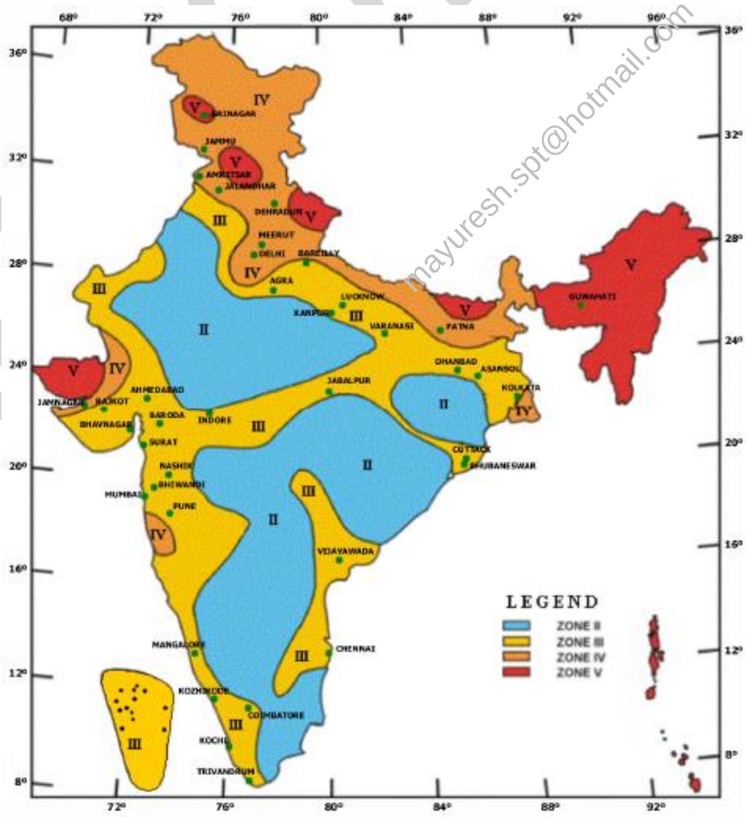

Figure 3: Seismic Zones of India

Student Notes:

The following table gives the distribution of various regions of the country into various seismic zones:

Zone	Damage risk	Region
Zone V	Very high damage risk zone	The entire North-east, including the seven sister states, the Kutch district, parts of Himachal and Jammu & Kashmir, and the Andaman and Nicobar islands.
Zone IV	High damage risk zone	Parts of the Northern belt starting from Jammu and Kashmir to Himachal Pradesh. Also including Delhi and parts of Haryana. The Koyna region of Maharashtra is also in this zone.
Zone III	Moderate damage risk zone	A large part of the country stretching from the North including some parts of Rajasthan to the South through the Konkan coast, and also the Eastern parts of the country.
Zone II	Low damage risk zone	These two zones are contiguous, covering parts of Karnataka, Andhra Pradesh, Orissa, Madhya Pradesh, and Rajasthan, known as low risk earthquake zones.

Table 4: Region falling in various zones of the country

1.6. Effects of Earthquakes

The direct and indirect effects of an earthquake includes:

1. **Deformed Ground Surface:** The earthquake tremors and the resultant vibrations, result in the deformation of the ground surface, due to the rise and subsidence of the ground surface and faulting activity. The alluvium filled areas of the flood plains may get fractured at several places.
2. **Damage to man-made structures:** Man-made structures such as buildings, roads, rails, factories, dams, bridges, etc., get severely damaged.
3. **Damage to towns and cities:** The towns and cities are the worst affected due to a high density of buildings and population. Under the impact of tremors, large buildings collapse and men and women get buried under the debris. Ground water pipes are damaged and thus water supply is totally disrupted.
4. **Loss of human and animal life:** The destructive power of an earthquake depends upon the loss it can cause in terms of loss of life arid property. The Bhuj earthquake of India in 2001 (8.1 on the Richter Scale) caused over one lakh human casualties.
5. **Devastating fires:** The strong vibrations caused by an earthquake can cause fire in houses, mines and factories due to the bursting of gas cylinders, contact with live electric wires, churning of blast furnaces, displacement of other electric and fire related appliances.
6. **Landslides:** The tremors in hilly and mountainous areas can cause instability of unconsolidated rock materials. This ultimately leads to landslides, which damage settlements and transport systems.
7. **Flash floods:** Very strong seismic events result in the collapse of dams and cause severe flash floods. Floods are also caused when the debris produced by tremors blocks the flow of water in the rivers. Sometimes the main course of the river is changed due to the blockage.
8. **Tsunamis:** When the seismic waves travel through sea water, high sea waves are generated, which can cause great loss to life and property, especially in the coastal areas.

2. Tsunami

Tsunami is a Japanese word which means ‘harbour wave’. It is a series of traveling ocean waves of extremely long length generated by disturbances associated primarily with earthquakes occurring below or near the ocean floor. Underwater volcanic eruptions and landslides can also generate tsunamis. Tsunamis are a threat to life and property to anyone living near the ocean. Large tsunamis have been known to rise over 100 feet, while tsunamis 10 to 20 feet high can be very destructive and cause many deaths and injuries.

Student Notes:

2.1. Causes

Tsunamis generally are caused by earthquakes. Not all earthquakes generate tsunamis. To generate tsunamis, earthquakes must occur underneath or near the ocean, be large and create movements in the sea floor. All oceanic regions of the world can experience tsunamis, but in the Pacific Ocean there is a much more frequent occurrence of large, destructive tsunamis because of the many large earthquakes along the margins of the Pacific Ocean.

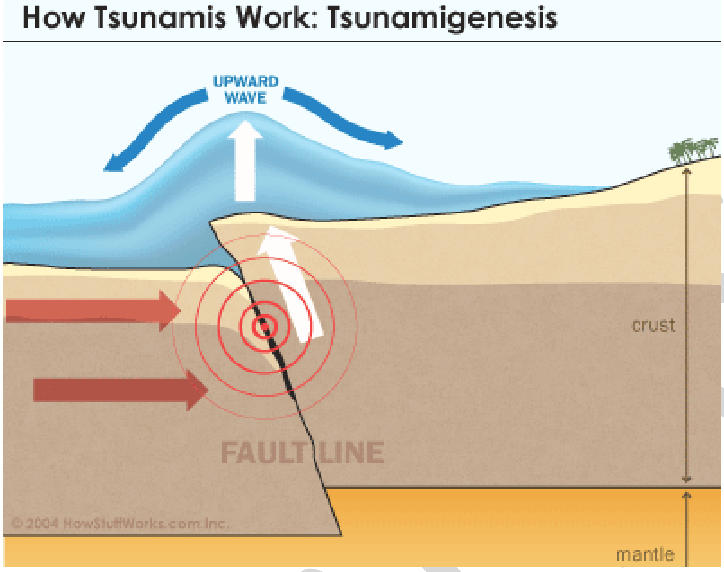

Figure 4: Generation of Tsunami

Other less common causes of earthquakes are **submarine landslides**, **submarine volcanic eruptions** and very rarely a **large meteorite impact in the ocean**.

2.2. Propagation

In the open ocean a tsunami is less than a few feet high at the surface, but its wave height increases rapidly in shallow water. Tsunamis wave energy extends from the surface to the bottom in the deepest waters. As the tsunami attacks the coastline, the wave energy is compressed into a much shorter distance creating destructive, life-threatening waves.

Where the ocean is over 20,000 feet deep, unnoticed tsunami waves can travel at the speed of a commercial jet plane, nearly 600 miles per hour. They can move from one side of the Pacific Ocean to the other in less than a day. This great speed makes it important to be aware of the tsunami as soon as it is generated. Scientists can predict when a tsunami will arrive since the speed of the waves varies with the square root of the water depth. Tsunamis travel much slower in shallower coastal waters where their wave heights begin to increase dramatically.

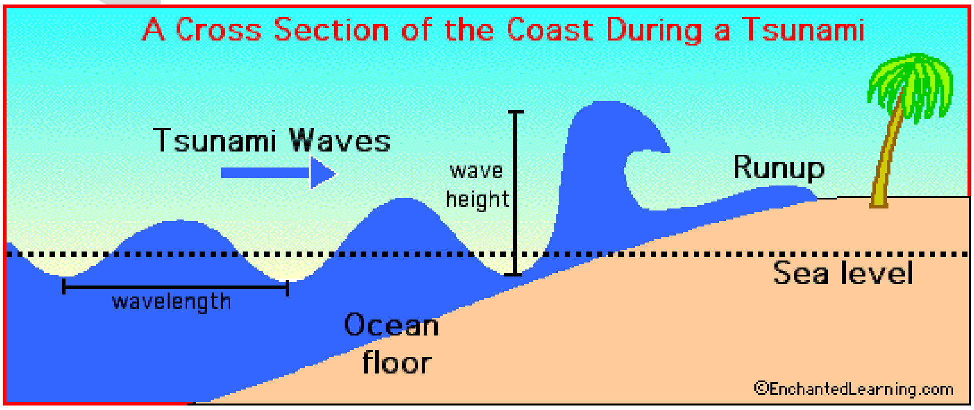

Figure 5: Rise in Tsunami amplitude near the coast

Offshore and coastal features can determine the size and impact of tsunami waves. Reefs, bays, entrances to rivers, under sea features and the slop of the beach all help to modify the tsunami as it attacks the coastline. When the tsunami reaches the coast and moves inland, the water level can rise many feet. In extreme cases, water level has risen to more than 50 feet for tsunamis of distant origin and over 100 feet for tsunami waves generated near the earthquake's epicentre.

2.3. Consequences

The consequences vary from loss of livelihood for fishermen to unknown damages to coral reefs and flora and fauna. It may take years for the coral reefs to get back the balance and mangrove stands and coastal tree plantations get destroyed or severely affected.

With so much sea water coming inland, salination is another effect that not only makes the soil less fertile to support vegetation but also increases vulnerability to erosion, the impacts of climate change and food insecurity. For humans, on the other hand, fisheries, housing and infrastructure are the worst affected.

2.4. Early Warning and Mitigation

Major tsunami warning centres are:

1. **Pacific Tsunami Warning Center (PTWC):** The Tsunami Warning System (TWS) in the Pacific, comprised of 26 participating international Member States, has the functions of monitoring seismological and tidal stations throughout the Pacific Basin to evaluate potentially tsunami genic earthquakes and disseminating tsunami warning information. The Pacific Tsunami Warning Center is the operational center of the Pacific TWS. Located near Honolulu, Hawaii, PTWC provides tsunami warning information to national authorities in the Pacific Basin.
2. **The Alaska Tsunami Warning Center (ATWC):** in Palmer, Alaska, serves as the regional Tsunami Warning Center for Alaska, British Columbia, Washington, Oregon, and California.
3. **Indian Tsunami Early Warning System (ITEWS):** The Indian Tsunami Early Warning System has the responsibility to provide tsunami advisories to Indian Mainland and the Island regions. Acting as one of the Regional Tsunami Advisory service Providers (RTSPs) for the Indian Ocean Region, ITEWS also provide tsunami advisories to the Indian Ocean Rim countries along with Australia and Indonesia.

In order to confirm whether the earthquake has actually triggered a tsunami, it is essential to measure the change in water level as near to the fault zone with high accuracy. There are two basic types of sea level gages: **coastal tide gages** and **open ocean buoys**.

Tide gages are generally located at the land-sea interface, usually in locations somewhat protected from the heavy seas that are occasionally created by storm systems. Tide gages that initially detect tsunami waves provide little advance warning at the actual location of the gage, but can provide coastal residents where the waves have not yet reached an indication that a tsunami does exist, its speed, and its approximate strength.

Open ocean tsunami buoy systems equipped with **bottom pressure sensors** are now a reliable technology that can provide advance warning to coastal areas that will be first impacted by a tsunami, before the waves reach them and near by tide gages. Open Ocean buoys often provide a better forecast of the tsunami strength than tide gages at distant locations.

Apart from technology, we can also use **natural barriers** to mitigate the effect of tsunamis. **Coral reefs** act as natural breakwaters, providing a physical barrier that reduces the force of a wave before it reaches the shore, while **mangrove forests** act as natural shock absorbers, also soaking up destructive wave energy and buffering against coastal erosion.

Student Notes:

3. Volcanoes

The word **volcano** is derived from the name of 'Vulcano', a volcanic island in the *Aeolian Islands* of Italy whose name in turn originates from 'Vulcan', the name of a god of fire in *Roman mythology*.

Volcano is a **vent** or an opening through which heated materials consisting of *water*, *gases*, *liquid lava* and *rock fragments* are erupted from the highly heated interior to the surface of the Earth. The layer below the solid crust of earth is **mantle**. It has higher density than that of the crust. The mantle contains a weaker zone called **asthenosphere**. It is from this that the molten rock materials find their way to the surface. The material in the upper mantle portion is called **magma**. Once it starts moving towards the crust or it reaches the surface, it is referred to as **lava**.

'*Volcanology'* or '*vulcanology'* is the term given to the study of volcanoes, and the scientists who study them are called the '*volcanologists*' or '*vulcanologists*'.

3.1. Vulcanicity

Vulcanicity includes all those processes in which molten rock material or magma rises to the crust to solidify as crystalline or semi-crystalline rocks. Some scientists use '*vulcanism*' as a synonym for vulcanicity.

Vulcanicity has two components; one of them operates below the crustal surface and the other above the crust, i.e. the endogenetic mechanism and the exogenous mechanism. The **endogenetic mechanism** includes the creation of hot and liquid magma and gases in the mantle and the crust, their expansion and upward ascent, their intrusion and cooling and solidification in various forms below the crustal surface. The **exogenous mechanism** includes the process of the appearance of lava, volcanic dust and ashes, fragmental materials, mud, smoke, etc., in different forms on the earth's surface.

3.1.1. Causes of Vulcanism

The mechanism of vulcanism and the volcanic activity are associated with several processes, such as:

1. A gradual increase of temperature with increasing depth at the rate of 1 degree Celsius for every 32 m.
2. Magma is formed due to the lowering of melting point, which in turn is caused by the reduction in pressure of the overlying material.
3. Gases and vapour are formed due to heating of water, which reaches underground through percolation.
4. The ascent of magma forced by vast volume of gases and water vapour.
5. The occurrence of volcanic eruption.

3.2. Components of a Volcano

The volcanoes of explosive type have a **volcanic cone**, which is formed when the erupted material accumulates around the vent. The **vent** is an opening of circular or nearly circular shape at the centre of the cone. The vent is connected to the interior of the earth by a **narrow pipe**. The volcanic materials erupt through this pipe. A funnel-shaped hollow at the top of the cone is called the **crater**.

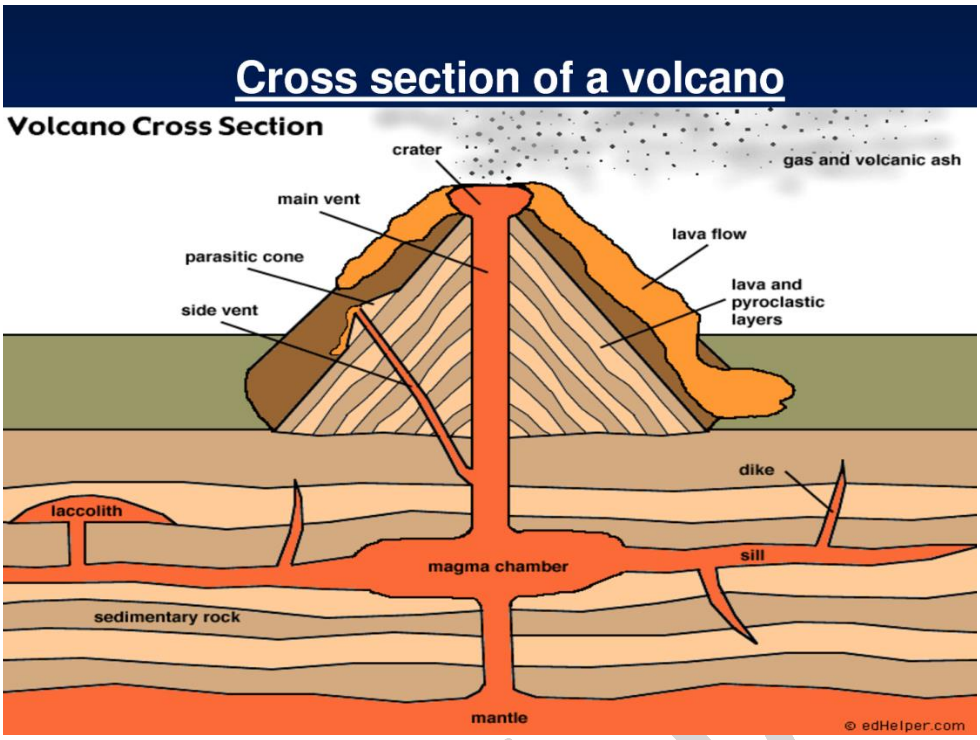

Figure 6: Components of a volcano

3.2.1. Types of lavas

There are two main types of lavas:

1. **Basic Lavas:** These are the hottest lavas and are *highly fluid*. They are dark coloured like *basalt*, rich in iron and magnesium but poor in silica. They flow quietly and are not very explosive. 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*.
2. **Acid Lavas:** 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 volcano is therefore *steep-sided*. The rapid cooling of lava in the vent obstructs the flow of the outpouring lava, resulting in loud explosions throwing out many *volcanic bombs* or *pyroclasts*.

Note: Pyroclasts are any volcanic fragment that was hurled through the air by volcanic activity.

3.3. Types of volcanoes

There is a wide variation in the mode of volcanic eruption and their periodicity. Accordingly the volcanoes can be classified on the basis of the mode of eruption and their periodicity of eruption.

Classification on the basis of mode of eruption: The volcanoes are classified into two groups on the basis of their *mode* of eruption:

1. **Violent or Explosive type:** The eruption of violent or explosive type is so rapid that huge quantities of volcanic materials are ejected thousands of metres in the sky. On falling, these materials accumulate around the volcanic vent and form volcanic cones. Such volcanoes are very destructive. They are generally associated with acidic lavas.
2. **Effusive or Fissure type:** The eruption of the fissure type of volcanoes-occurs along a long fracture, fault or fissure. Magma ejects slowly and the resultant lava spreads on the surface.

Student Notes:

The speed of the lava flow depends on the nature and volume of magma, slope of the ground and the temperature conditions.

Classification on the basis of periodicity of eruption: The volcanoes are divided into three types on the basis of the periodicity of their eruption:

1. **Active Volcanoes:** Volcanoes are said to be active when they frequently erupt or at least when they have erupted within recent time. Etna and Stromboli are typical examples.
2. **Dormant Volcanoes:** Volcanoes that have been known to erupt and show signs of possible eruption in future are described as dormant. Mt. Vesuvius is the best example.
3. **Extinct Volcanoes:** Volcanoes that have not erupted at all in historic times but retain the features of volcanoes are termed extinct. Ship rock in Netherlands is one such example.

All volcanoes pass through active, dormant and extinct stages but it is impossible to be thoroughly sure when a volcano has become extinct.

3.4. Volcanic Landforms

Various landforms are created due to the cooling and solidification of magma (below the Earth's surface) and lava (on the Earth's surface). Some relief features are formed due to the accumulation of volcanic materials. The volcanic landforms are grouped into two broad categories: **Extrusive** landforms and **Intrusive** landforms.

3.4.1. Extrusive Landforms

Extrusive landforms are determined by the nature and composition of the lava. Major extrusive landforms are as under:

1. **Cinder or ash cones** are formed due to the accumulation of loose particles around the vent. Its size increases due to the continuous accumulation of volcanic material minus lava. The larger particles are arranged near the crater and the finer particles are deposited at the outer margins of the cone. The lava flows are so viscous that they solidify after a short distance.
2. **Composite cones** are the highest and are formed by the accumulation of various layers of volcanic material. They have alternate layers of lava and fragmented material, wherein lava acts as the cementing material. These are mainly associated with cooler and more viscous lava and the volcanoes associated with them are called **composite volcanoes**.
3. **Shield Volcanoes** are built almost entirely of fluid lava flows**.** They are named for their large size and low profile, resembling a warrior's shield lying on the ground. Barring the basalt flows, the shield volcanoes are the largest of all the volcanoes on the earth. These volcanoes are mostly made up of basalt, a type of lava that is very fluid when erupted. For this reason, these volcanoes are not steep.
4. **Craters** are depressions formed at the mouth of the volcanic vent, which is usually funnel-shaped. Some volcanoes may have greatly enlarged depressions called **calderas**. These are the result of violent eruptions accompanied by the subsidence of much of the volcano into the magma beneath. Water may collect in the crater or the caldera forming crater or caldera lakes.
5. **Flood Basalt Provinces** are formed when volcanoes outpour highly fluid lava that flows for long distances. Some parts of the world are covered by thousands of sq. km of thick basalt lava flows. There can be a series of flows with some flows attaining thickness of more than 50 m. Individual flows may extend for hundreds of km. The *Deccan Traps* from India, presently covering most of the Maharashtra plateau, are a much larger flood basalt province.

Student Notes:

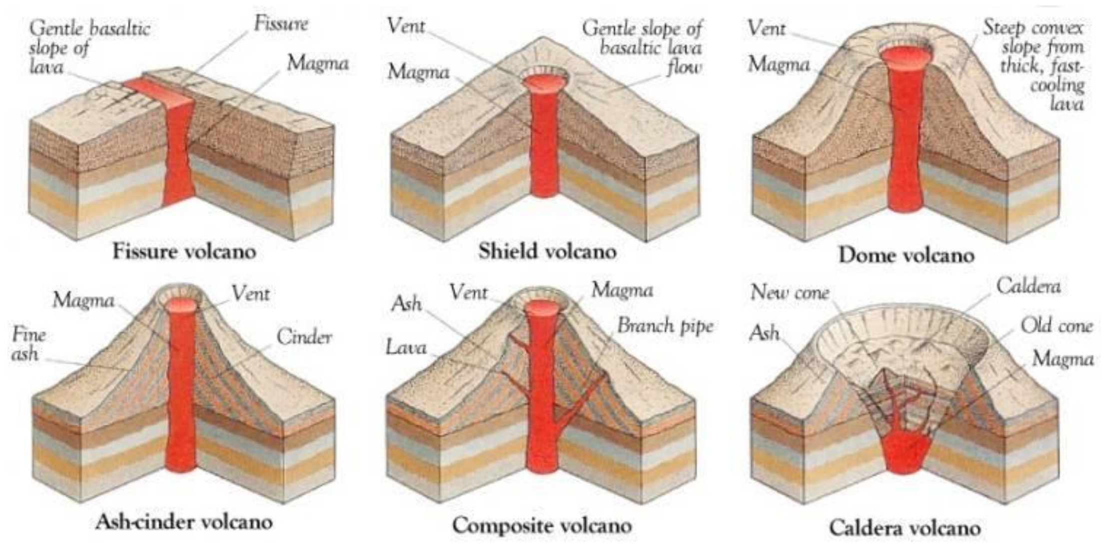

Figure 7: Volcanoes based on extrusive landforms

3.4.2. Intrusive Landforms

The lava that cools within the crustal portion assumes different forms called intrusive forms. Some of these forms are:

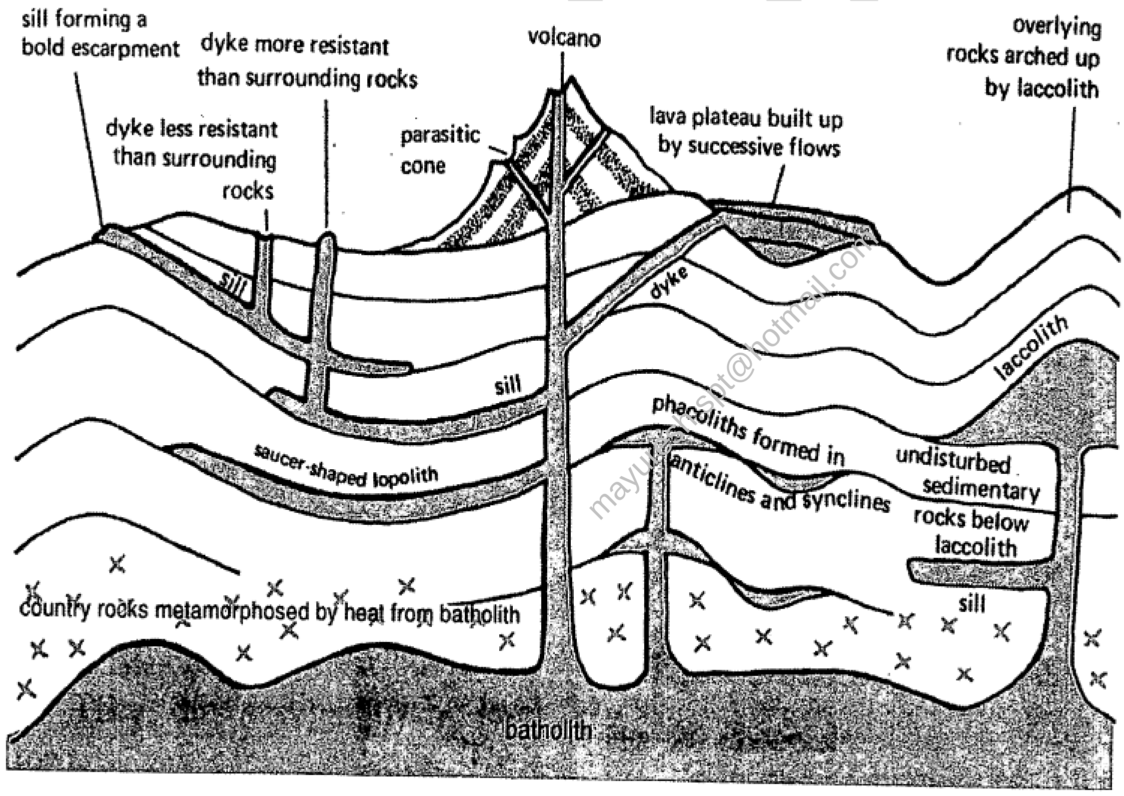

Figure 8: Various intrusive landforms formed in volcanic regions

1. **Batholiths** are long, irregular, undulating and dome-shaped features. They are a large body of magmatic material that cools in the deeper depth of the crust and develops in the form of large domes. They appear on the surface only after the denudational processes remove the overlying materials. They cover large areas, and at times, assume depth that may be several km. These are granitic bodies. Batholiths are the cooled portion of magma chambers.

Student Notes:

2. **Laccoliths** are formed due to the intrusion of magma along the bedding planes of horizontal sedimentary rocks. They are usually mushroom or dome shaped.
3. **Phacoliths** are formed due to the intrusion of acidic magma along the anticlines and synclines in the region of fold mountains.
4. **Lapoliths** are formed when magma solidifies in shallow basins into a saucer shape.
5. **Sills** and **Sheets** are intrusive igneous rocks usually parallel to the bedding planes of sedimentary rocks. Depending on the thickness of deposits, thinner ones are called **sheets** while thick horizontal deposits are called **sills.**
6. **Dykes** are wall-like formation of solidified magma. These are vertical to the bed of sedimentary rocks. The thickness ranges from a few centimetres to several hundred metres, but the length can be several kilometres.

3.5. Distribution of Volcanoes

The volcanoes are mostly associated with the weaker zones of the Earth's crust which are also zones of seismic activities like the earthquakes. The weaker zones are mostly found in the areas of fold mountains. They are also associated with the meeting zones of oceans and continents, or with the mountain building activity.

Most of the world's active volcanoes are associated with the plate boundaries. About 15 per cent of the volcanoes are associated with the divergent plate boundaries and about 80 per cent with the convergent plate boundaries. Some volcanoes are also found in the intra-plate regions.

The main volcanic belts are as under:

1. **Circum-Pacific Belt:** It includes the volcanoes of the eastern and western coastal areas of the Pacific Ocean. This belt is also known as the **Ring of Fire** of the Pacific Ocean.

   It begins from Erebus mountains of Antarctica and runs northwards through Andes of South America and Rockies of North America to reach Alaska. From there, it turns eastwards along the coast of Asia to include the volcanoes of Sakhalin and Kamchatka, Japan and Philippines respectively. This belt finally merges with the Mid-continental Belt in Indonesia.

   Most of the high volcanic cones and volcanic mountains are found in the Circum-Pacific Belt. *Cotopaxi* in Andes (5896 m) is the highest volcanic mountain in the world. The other famous volcanoes are *Fujiyama* (Japan), *Shasta*, *Rainier*, *Mt St Helena* (USA).

2. **Mid-Continental Belt:** It includes the volcanoes of the Alpine mountains and the Mediterranean Sea. The volcanic eruptions are caused due to the convergence and collision of the Eurasian Plates and the African and Indian Plates. Some of the famous volcanoes of the Mediterranean Sea such as the *Stromboli*, *Vesuvius*, *Etna*, etc., are in this belt. This belt is not continuous and has several volcanic free zones such as the Alps and the Himalayas. The important volcanoes in the fault zone of eastern Africa are *Kilimanjaro*, *Meru*, *Elgon*, *Rungwe*, etc.

3. **Mid-Atlantic Belt:** It includes the volcanoes along the mid-Atlantic ridge which is the divergent plate zone. They are mainly of the fissure eruption type. Iceland, is the most active volcanic area.

Student Notes:

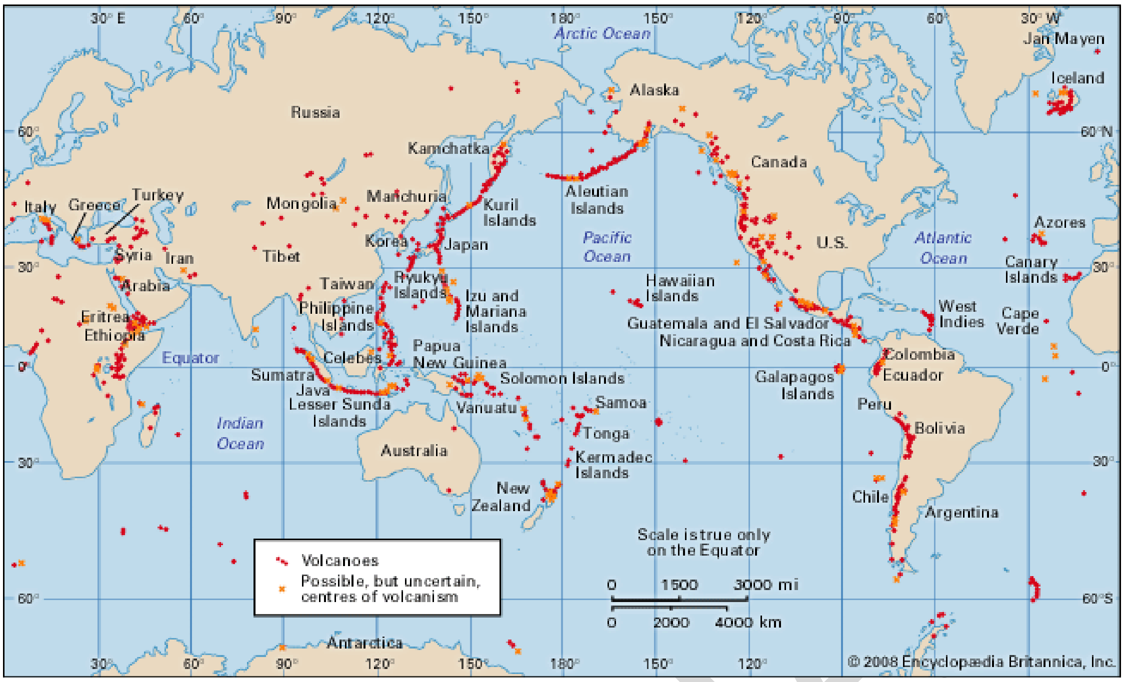

Figure 9: Distribution of volcanoes

3.6. Effects of volcanic eruptions

Volcanic eruption causes heavy damage to human life and property. Some of them are as under:

- Large volumes of hot lava moving at a fast speed can bury man-made buildings, kill people and animals, destroy agricultural farms and pastures, burn and destroy forests.
- The fall out of large quantities of fragmented materials, dust, ash, smoke, etc., creates health hazards due to poisonous gases emitted during eruption. It also causes **acid rain**.
- If the explosive eruption has occurred suddenly, the human beings get no time to escape to safer places. Heavy rains mixed with volcanic dust and ash cause enormous mud-flow on the steep slopes of the cones.
- Earthquakes caused due to explosive eruptions can generate destructive tsunamis, seismic waves, etc. These can cause loss of life and property in the affected coastal regions.
- The volcanic eruptions can change the heat balance of the Earth and the atmosphere, causing climatic changes.

But there are many **positive effects** also. Some of them are:

- Lava can give rise to fertile soils. Most of the precious stones are formed due to volcanic activity.
- Geysers and springs are tourist attraction and are also important from the medical point of view due to the chemicals dissolved in them.
- Some crater lakes are source of rivers and often offer scenic attraction for tourists.
- Most of the volcanic rocks when exposed on the surface are a storehouse of metals and minerals.

3.7. Geysers

Geysers are *fountains of hot water* and superheated steam that may spout up to a height of 150 feet from the earth beneath. The phenomena are associated with a thermal or volcanic region in which the water below is being heated beyond boiling point. The jet of water is usually emitted with an explosion, and is often triggered by gases seeping out of the heated rocks.

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

3.8. Hot Springs

Hot springs or thermal springs are more common, and may be found in any part of the earth where water sinks deep enough beneath the surface to be heated by the interior forces. The water rises to the surface without any explosion. Such springs contain dissolved minerals which have medical value.

Iceland has thousands of hot springs. Hot springs are common in many parts of India, especially in the hilly and mountainous parts. Some of them are in Manikaran (Kulu), Tattapani (Shimla), Jwalamukhi (Kangra), Rajgir (Patna), Sitakund (Munger) and in Yamunotri and Gangotri.

3.9. Fumaroles

A fumarole is a vent in the Earth's surface which emits gases and water vapour. Sometimes the emission is continuous, but in majority of cases emission occurs after intervals. It is widely believed that gases and water vapour are generated due to cooling and contraction of magma after the eruption. Fumaroles are the last signs of the activeness of a volcano.

MOUNTAIN BUILDING ISLAND FORMATIONS AND HOTSPOTS

Contents

1. Mountains

Since the dawn of geological time, no less than nine **orogenic** or mountain building movements have taken place, folding and fracturing the earth's crust. Some of them occurred in Pre-Cambrian times about 600-3,500 million years ago. The three more recent orogenies are the **Caledonian**, **Hercynian** and **Alpine**. The *Caledonian* about 320million years ago raised the mountains of Scandinavia and Scotland, and is represented in North America. These ancient mountains have been worn down and no longer exhibit the striking forms that they must once have had.

In a later period, during the *Hercynian* earth movements, about 240 million years ago, were formed such ranges as the Ural Mountains, the Pennines and Welsh Highlands in Britain, the Harz Mountains in Germany and the Appalachians in America. These mountains have also been reduced in size by the various sculpturing forces.

The last of the major orogenic movements of the earth, the *Alpine*, occurred about 30 million years ago. Young fold mountain ranges were formed on a gigantic scale. Being the most recently formed, these ranges, such as the Alps, Himalayas, Andes and Rockies are the loftiest and the most imposing. Their peaks are sometimes several miles high.

1.1. Types of Mountains

Based on their mode of formation, **four** main types of mountains can be distinguished:

1.1.1. Fold Mountains

These mountains are the most widespread and also the most important. They are caused by large-scale earth movements, when *stresses* are set up in the earth's crust. Such stresses may be due to:

- the increased load of the overlying rocks,
- flow movements in the mantle,
- magmatic intrusions into the crust, or
- the expansion or contraction of some part of the earth.

When such stresses are initiated, the rocks are subjected to **compressive forces** that produce *wrinkling* or *folding* along the lines of weakness. As illustrated in Fig.1 and 2, folding effectively shortens the earth's crust, creating from the original level surface a series of 'waves'.

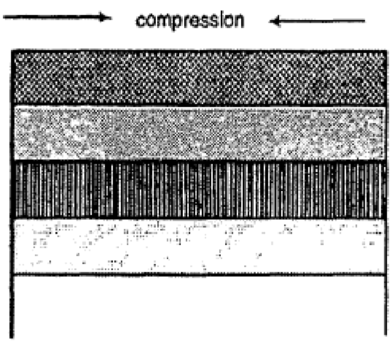

Fig.1 Earth's crust before folding

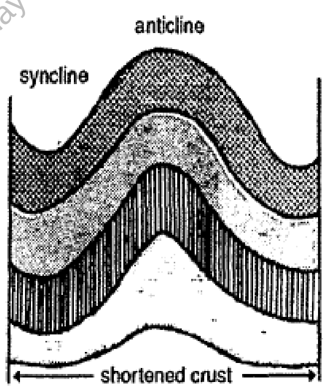

Fig.2 Earth's crust after folding

The upfolded waves are called **anticlines** and the troughs or downfolds are called **synclines**. Due to the complexity of the compressional forces, thefolds may develop much more complicated forms. When the *crest* of a fold is pushed too far, an *overfold* is formed (Fig.3). If it is pushed still further, it becomes a *recumbent fold*. In extreme cases, fractures may occur in the crust, so that the upper part of the recumbent fold slides forward over the lower part along a thrust plane forming an *over thrust fold*. The over-riding portion of the thrust fold is termed a *nappe*.

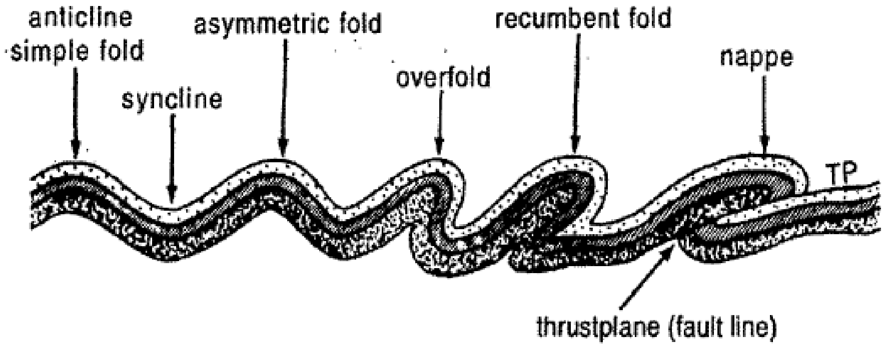

Fig. 3 Types of Folding

Since the rock strata have been elevated to great heights, sometimes measurable in miles, fold mountains maybe called *mountains of elevation*. The fold mountains are also closely associated with volcanic activity. They contain many active volcanoes, especially in the Circum-Pacific fold mountain system. They also contain rich mineral resources such as tin, copper, gold and petroleum.

Characteristics

- Fold mountains are the **youngest** mountains on the surface of the Earth.
- Young folded mountains represent the **highest** mountains on the earth. They also have the highest mountain summits. Mt. Everest is the most typical example (8848m).
- Fold mountains have been formed due to the folding of **sedimentary** rocks formed due to the deposition and consolidation of sediments in water bodies mainly in the oceanic environment.
- The sedimentary rocks of the fold mountains were deposited in shallow seas. The greater thickness of sediments is possible due to the continuous sedimentation and subsidence.
- The **length** of the fold mountains is **much more than their width**. The east-west extent of the Himalayas is about 2400 km, but their north-south width is only 400 km. Thus the fold mountains must have been formed in long, narrow and shallow seas.
- Fold mountains are generally **arc-shaped**, having a concave slope on one side and convex on the other.
- Fold mountains are found along the **margins of the continents facing ocean** such as the Andes and the Rockies. If we consider the former Tethys Sea, then the Himalayas are also located along the margins of the continent.
- Fold mountains are mostly located in **two directions**. In the north-south direction lie the Rockies and the Andes, while in the west-east direction lie the Himalayas and the Alps.

Human activity surrounding fold mountains

- Winter sports such as skiing in resorts.
- Climbing and hiking in the summer months.
- Agriculture - takes place mainly on south facing slopes and includes cereals, sugar beet, vines and fruits.
- Forestry - coniferous forests for fuel and building.
- Communications - roads and railways follow valleys.
- Hydroelectric power (HEP) - steep slopes and glacial melt water are ideal for generating HEP. Hydroelectric accounts for 60 per cent of Switzerland's electricity production.

Student Notes:

1.1.2. Block Mountains

When the earth's crust bends, **folding** occurs, but when it cracks, **faulting** takes place. Faulting may be caused by tension or compression, forces which lengthen or shorten the earth's crust, causing a section of it to subside or to rise above the surrounding level.

Earth movements generate tensional forces that tend to pull the crust apart (fig. 4), and *faults* are developed. If the block enclosed by the faults remains as it is or rises, and the land on either side subsides, the upstanding block becomes the ***horst* or** block mountain. The faulted edges are very steep, with scarp slopes and the summit is almost level, e.g. the Hunsruck Mountains, the Vosges and Black Forest of the Rhineland.

Tension may also cause the central portion to be let down between two adjacent fault blocks forming a **graben** or rift valley, which will have steep walls. The East African Rift Valley system is 3,000 miles long, stretching from East Africa through the Red Sea to Syria.

Compressional forces set up by earth movements may produce a thrust or reverse fault and shorten the crust. A block may be raised or lowered in relation to surrounding areas. Fig.5 illustrates a rift valley formed in this way. In general large-scale block mountains and rift valleys are due to tension rather than compression.

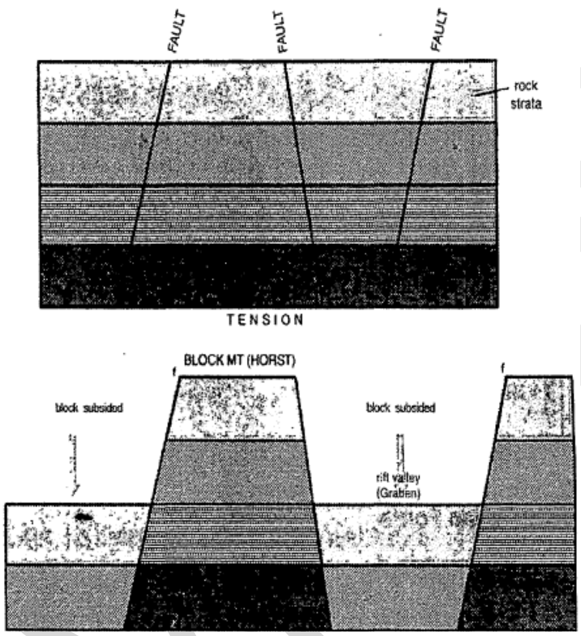

Fig. 4 Block Mountains formed by tensional forces

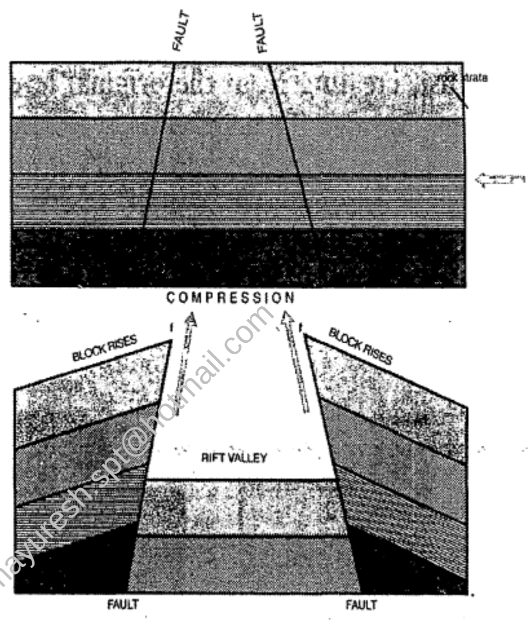

Fig.5 Rift Valley formed by compressive forces

1.1.3. Volcanic Mountains

These are built up from material ejected from fissures in the earth's crust. The materials include molten lava, volcanic bombs, cinders, ashes, dust and liquid mud. They fall around the vent in successive layers, building up a characteristic volcanic cone (Fig. 6). Volcanic mountains are often called *mountains of accumulation*. They are common in the Circum-Pacific belt and include such volcanic peaks as Mt. Fuji (Japan), Mt. Mayon (Philippines), Mt. Merapi (Sumatra), Mt. Agung (Bali) and Mt. Catopaxi (Ecuador).

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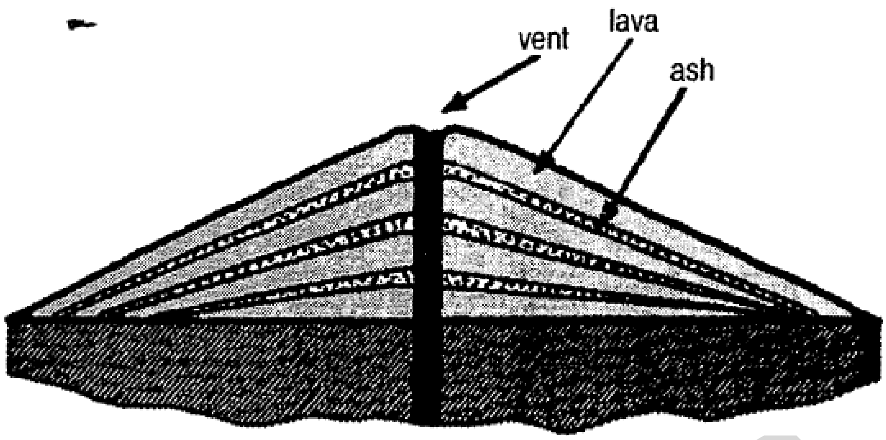

Fig. 6 Volcanic Mountains

1.1.4. Residual Mountains

These are mountains evolved by *denudation*. Where the general level of the land has been lowered by the agents of denudation some very resistant areas may remain and these form residual mountains, e.g. Mt. Manodnock in U.S.A. Residual mountains may also evolve from plateaux which have been dissected by rivers into hills and valleys like. In these type of mountains, the ridges and peaks are all very similar in height.

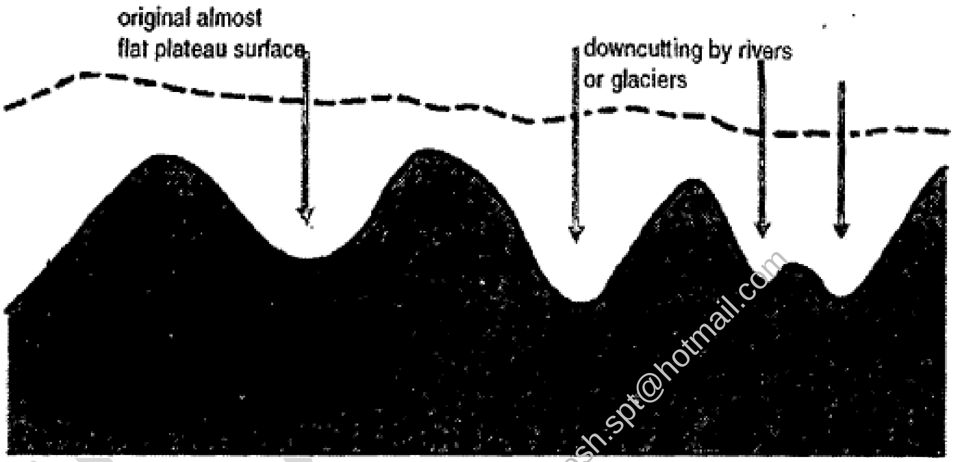

Fig. 7 Residual Mountains

2. Islands

An island is a piece of land surrounded on all sides by water. It may occur *individually or in a group*, in open oceans or seas. Smaller ones of only local significance are found even in lakes and rivers. Generally speaking all islands may be grouped, based on their *mode of formation*, under the following two broad types.

2.1. Continental Islands

These islands were formerly part of the mainland and are now detached from the continent. They may be separated by a shallow lagoon or a deep channel. Their separation could be due to subsidence of some part of the land or to arise in sea level, so that the lowland links are submerged by the sea.

Their former connection with the neighbouring mainland can be traced from the similar physical structure, flora and fauna that exist on both sides of the channel. In the course of time, modification by men and other natural forces may give rise to different surface features. Continental islands can be further classified as under:

Student Notes:

1. **Individual Islands:** These lie just outside the continent, very much associated with the characteristic features of the mainland of which they were once part. Some of the outstanding examples are New foundland, separated from the mainland by the Strait of Belle Isle; Madagascar, by the Mozambique Channel.
2. **Archipelagoes or island groups**: These comprise groups of islands of varying sizes and shapes, e.g. the British Isles, the Balearic Islands of the Mediterranean and also those of the Aegean Sea.
3. **Festoons or island arcs:** The islands form an archipelago in the shape of a loop around the edge or the mainland, marking the continuation of mountain ranges which can be traced on the continent. Most of these island arcs are formed as one oceanic tectonic plate subducts another one and, in most cases, produces magma at a depth below the overriding plate, e.g. Andaman and Nicobar Islands, the East Indies, the Aleutian Islands, RyukyuIs lands, Kurile Islands and other island arcs of the Pacific coasts.

2.2. Oceanic Islands

These islands are normally small and are *located in the midst of oceans*. They have no connection with the mainland which may be hundreds or thousands of miles away. They have a flora and fauna unrelated to those of the continents. Due to their remoteness from the major trading centres of the world, most of the oceanic islands are very sparsely populated. Some of them provide useful stops for aeroplanes and ocean steamers that ply between continents across vast stretches of water.

Oceanic Islands can be further classified as under:

1. **Volcanic islands**: Many of the islands in the oceans are in fact the topmost parts of the *cones of volcanoes* that rise from the ocean bed. Most of them are extinct, but there are also some active ones. The best known volcanic peak of the Pacific Ocean is **Mauna Loa** in Hawaii Other volcanic islands have emerged from the submarine ridges of the oceans.
   The volcanic islands are scattered in most of the earth's oceans.
   - In the Pacific Ocean, they occur in several groups such as Hawaii, the Galapagos Islands (Ecuador) and the South Sea islands.
   - In the Atlantic are the Azores (Portugal), Ascension, St. Helena[1], Madeira (Portugal) and the Canary Islands (Spain).
   - In the Indian Ocean, there are Mauritius and Reunion (French Island in Indian Ocean).
   - In the Antarctic Ocean are the South Sandwich Islands and Bouvet Island.
2. **Coral islands:** Unlike the volcanic islands, the coral islands are very much lower and emerge just above the water surface. These islands, built up by coral animals of various species, are found both near the shores of the mainland and in the midst of oceans. Coral islands include:
   - Marshall Islands, Gilbert (Kiribati) and Tuvalu (formerly Ellice Islands) of the Pacific.
   - Bermuda (British Overseas Territory) in the Atlantic.

Laccadives and Maldives of the Indian Ocean.

[1] Saint Helena, Ascension and Tristan da Cunha is a British Overseas Territory in the southern Atlantic Ocean consisting of the island of Saint Helena, Ascension Island and the island group called Tristan da Cunha.

Student Notes:

<u>Artificial Island</u>

An artificial island is a man-made island, created by expanding existing islets, building on existing reefs or making them from scratch, off the coastline. Man has been building such islands for hundreds of years. The Flevopolder in the Netherlands is the largest artificial island in the world.

In News (The Hindu June 2012): Israeli politicians are floating an idea to expand their seaside country — artificial islands.

Palm Islands

The **Palm Islands** are two artificial islands in Dubai, United Arab Emirates in the shape of palm trees. The islands are the Palm Jumeirah and the Palm Jebel Ali.

Climate change has hit islands hard with some in danger of disappearing completely as sea levels rise. The world's first underwater cabinet meeting organised by the Maldivian president on 17 October 2009 was a symbolic cry for help over rising sea levels that threaten the tropical archipelago's existence

Fig: Palm Islands

Importance of Islands

- Earth's 175,000 islands are home to more than 600 million inhabitants
- Islands and their oceans represent one-sixth of earth's total area
- Islands support many of the most unique and isolated natural systems including:
    - more than half the world's marine biodiversity
    - 7 of the world's 10 coral reef hotspots
    - 10 of the 34 richest areas of biodiversity in the world
- 64% of recorded extinctions are on islands
- Over two-thirds of the world's countries include islands.
- Island ecosystems provide food, fresh water, wood, fibre, medicines, fuel, tools and other important raw materials, in addition to aesthetic, spiritual, educational and recreational values. In fact, the livelihood and economic stability of the islands depend on its biodiversity.

3. Hotspots[2]

A hot spot is a very hot region deep within the Earth. It is usually responsible for volcanic activity. They may be unanimously hot, and provide a great deal of molten magma. Hot spots do not always create volcanoes that spew rivers of lava. Sometimes, the magma heats up groundwater under the Earth's surface, which causes water and steam to erupt like a volcano. These eruptions are called *geysers*.

There are 40 to 50 hot spots around the world, including near the Galapagos Islands (Ecuador) and Iceland. Hot spots can create entire chains of islands, like the U.S. state of Hawaii. Hawaii is on the Pacific plate, an enormous section of the Earth in the Pacific Ocean that is constantly moving, but very, very slowly. Although the plate is always moving, the hot spot underneath it stays still. The hot spot spewed magma that eventually became a chain of islands that rose over the surface of the water. These islands were created one right after the other as the plate moved, almost like an island factory.

Scientists use hot spots to track the movement of the Earth's plates.

[2] Biodiversity hotspot, a region of significant biodiversity is different thing.

Student Notes:

ROCKS AND MINERALS

Contents

Student Notes:

1. Introduction

Rocks and minerals make up the Earth's crust. Crust or the lithosphere is the thin outermost layer of the Earth.

The hard resistant materials of the crust are called rocks. But in scientific terms, rocks include not only the hard materials such as granite, sandstone and marble, but also soft and loose materials such as chalk, clay, sand, salt and coal.

2. Minerals

Minerals are those substances which occur **naturally** in rocks. These are non-living solid substances which have a definite chemical composition.

Minerals are often classified as metallic and non metallic. The surface of the metallic minerals is generally slippe and glossy. Gold, copper and lead are metallic minerals. They are melted to obtain metals. The surface of the non metallic minerals is dull. They cannot reflect the sun-rays. Gypsum, quartz and mica are non-metallic minerals. Metals cannot be obtained from these minerals.

Rocks and minerals account for about 99 per cent of the materials found in the outer layer of the lithosphere. Some rocks have useful minerals, which provide us with metals and chemicals.

Out of about 2000 different minerals, only 12 are known as the rock-forming minerals. Oxygen and silicon account for about 75 per cent of the Earth's crust by weight. These elements are essential for plant and animal life on the Earth.

PHYSICAL CHARACTERISTICS OF MINERALS: Minerals have distinct physical properties that can be used to correctly identify a mineral. These are

- Crystal structure: arrangement of atoms inside mineral
- Hardness: on the Mohs scale, a ten-point scale running from the softest, talc to the hardest, diamond.
- Lustre: appearance in light
- Colour
- Streak: colour of a mineral when it has been ground to a fine powder. Often tested by rubbing the specimen on an unglazed plate.
- Cleavage: how mineral splits along various planes
- Fracture: how it breaks against its natural cleavage planes
- Specific gravity: density compared with water

2.1. Some Major Minerals and Their Characteristics

Minerals	Composition	Importance	Other facts
Feldspar	Common fieldspar silicon and oxygen. Specific fieldspar sodium, potassium, calcium, aluminium .	Used in ceramics and glass making	Half of the earth's crust is composed of feldspar
Quartz	Consists of silica.	Prominent components of Sand and Granite and used in Radio and Radar	Hard mineral virtually insoluble in water.
Pyroxene	Pyroxene consists of calcium, aluminum, magnesium, iron and silica.	commonly found in meteorites	Pyroxene forms 10 per cent of the earth's crust.

Student Notes:

Amphibole	Aluminum, calcium, silica, iron, magnesium are the major elements of amphiboles.	used in asbestos industry Hornblende is another form of amphiboles	They form 7 per cent of the earth's crust
Mica	It comprises of potassium, aluminium, magnesium, iron, silica etc	used in electrical instruments	It forms 4 percent of the earth's crust. It is commonly found igneous and metamorphic rocks.
Olivine	Magnesium, iron and silica are major elements of olivine.	Used in jewellery	Found in basaltic rocks.

3. Rocks

Rocks are generally a mixture of two or more minerals and do not possess a definite chemical composition.

3.1. Major Types of Rocks

On the basis of their mode of formation, rocks can be classified into the following three types:

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

3.1.1. Igneous Rocks

The word igneous is derived from the Latin word 'ignis' meaning fire. These rocks are of thermal origin and are associated with volcanic eruptions. These rocks have been formed due to solidification of hot and molten material called magma.

It is believed that at the time of its birth the Earth was in a molten state. The igneous rocks were the first to be formed as a result of the solidification of the outer layer of the Earth. Thus, igneous rocks are also known as the primary rocks. They can be divided into two types—**intrusive[1] igneous rocks** and **extrusive igneous rocks**.

Igneous rocks that cool below the surface of the Earth are called **intrusive igneous rocks**. The rate of cooling is slow inside the Earth. Thus the crystals formed on cooling are large. Two common examples of intrusive rocks are dolerite and granite.

Igneous rocks that cool on the surface of the Earth are called **extrusive igneous rocks**. These rocks are also known as volcanic rocks. Due to rapid cooling, the crystals are fine grained such as in basalt.

On the basis of their composition the igneous rocks are also classified as **acidic** Igneous Rocks and **Basic** igneous rocks. In **Acidic Igneous rocks silica content in rocks is more** than 65 per cent. These rocks are light colored and have less density. These are also known as 'Silicic rocks'. Granite and rhyolite are examples of these rocks. In **Basic Igneous rocks** the silica content is less than 65 per cent. They are composed predominantly of ferromagnesian minerals (rich in iron and magnesium). They are dark coloured and dense. **Gabbro** and **basalt** are basic rocks.

[1] Igneous rock bodies will be discussed in chapter on volcanoes.

Student Notes:

Characteristics of igneous rocks

- They are compact and massive and do not possess rounded particles.
- They do not occur in distinct beds or stratas.
- They are generally granular and crystalline.
- They are hard and impermeable.
- They are less affected by chemical weathering.
- They do not contain any fossils or traces of animals or plants.
- Most of the igneous rocks consist of silicate minerals.
- The valuable minerals such as iron, gold, silver, aluminium, etc., are found in them.

Economic Importance of Igneous Rocks

- They are a reservoir of minerals.
- Majority of metallic minerals are found in igneous rocks.
- Economically important minerals are found in these rocks-Magnetic iron, nickel, copper, lead, zinc, chromite, manganese, tin.
- Rare minerals like gold, diamonds, platinum are also found in these rocks.
- Basalt and granite are used for construction of buildings and roads.
- The formation of black soils is probably the result of erosion of these rocks. These soils are very much suited to cultivation of cotton and some other crops.

3.1.2. Sedimentary Rocks

The word sedimentary has been derived from the Latin word 'sedimentum', meaning settling down.

Rain, wind, ice, running water, plants and animals constantly break the rocks into fragments of all sizes. These broken rock materials are carried away by wind, ice and running water, and deposited in the depressions. The deposited materials are called sediments, and they give rise to sedimentary rocks.

The sediments are generally deposited in horizontal layers or stratas. Thus these rocks are also referred to as stratified rocks. The loose materials are converted into hard and compact rocks such as shale and sandstone. This is due to the pressure exerted from the top or because of cementation.

The sedimentary rocks can be formed mechanically (sandstone), chemically (gypsum or salt) or organically (coal, limestone). The sedimentary rocks are most widespread and cover about 75 per cent of the total land area on the earth.

Characteristics of sedimentary rocks

- They are comparatively softer than the igneous rocks.
- They are made up of minute particles of various shapes and sizes.
- They have layers horizontally arranged one above the other.
- They have been mostly formed under water.
- They have mud cracks and marks of ripples and waves.
- They have fossils between the layers.
- Most of them are permeable and porous.
- Of all the sedimentary deposits, coal and petroleum are the most important ones.
- Modern industries depend on the products from the sedimentary rocks.

Economic Importance of Sedimentary Rocks

- It is true that they contain lesser minerals than in the igneous rocks. But iron ore, phosphates, building stones, coal, raw materials for cement and bauxite are obtained from these.
- Mineral oil and Natural Gas is also obtained from sedimentary rocks. In India there is a possibility of finding oil fields in the sedimentary rock strata of the sub-Himalayan zone, in the delta regions of Ganga, Kaveri, Godavari and Krishna rivers, Rann of Kutch and the Gulf of Khambhat. The mineral oil commonly known as petroleum is formed by the decay of **tiny marine organisms (in contrast Coal is formed from dead plant**) between to impermeable rocks.
- Sandstone, limestone are used in construction of buildings. The forts of Agra, Delhi and Fatehpur Sikri are built of red sandstone
- Fertile Soils: The Indus and Ganga basins are also made of sedimentary rocks. Their alluvial soils are highly fertile.

3.1.3. Metamorphic Rocks

The word metamorphic means 'changed form'. The rocks, originating at or near the surface of the Earth are sometimes subjected to tremendous heat and pressure. This can change the original properties of rocks such as their colour, hardness, texture and mineral composition. Such changed rocks are called metamorphic rocks. Both igneous and sedimentary rocks can change into metamorphic rocks. The special feature about the origin and formation of metamorphic rocks is that they remain in their original position and change under the impact of internal and external forces. Metamorphism can be of thermal and dynamic origin.

1. In the case of thermal metamorphism, the original rocks are changed under the influence of high temperature inside the Earth's crust. For example, limestone is converted into marble, sandstone into quartzite, shale into slate and coal into graphite.
2. In the case of dynamic metamorphism, the original rocks are changed under the influence of pressure at great depths inside the Earth's crust. For example, granite is converted into gneiss and shale into schist.

Characteristics of metamorphic rocks

- They are usually hard.
- They have a high specific gravity.
- They may be banded.
- They do not have void spaces in them.

Parent Rock and its Metamorphic Changed Form

NAME OF THE ROCK	TYPE OF ROCK	NAME OF THE METAMORPHIC ROCK
Limestone	Sedimentary Rock	Marble
Dolomite	Sedimentary Rock	Marble
Sandstone	Sedimentary Rock	Quartzite
Shale	Sedimentary Rock	Slate
Slate	Metamorphic Rock	Phylite/Schist
Coal	Sedimentary Rock	Graphite/Diamond
Granite	Igneous Rock	Gneiss
Phyllite	Metamorphic Rock	Schist

Student Notes:

Economic Importance of Metamorphic Rocks

1. **Building Construction Materials**: Gneiss, quartzite, slate, marble are used as building materials. In India marble is found in Alwar, Ajmer, Jodhpur and Jaipur districts of Rajasthan. The thick sheet of slate is used for laying the surface of billiards table. Slate is found in parts of Riwari (Haryana), Karigra (H.P) and Bihar.
2. **Industrial Uses**: Graphite is used for making pencils. Its melting point is 3500°C. Therefore pots for melting of metals are made of graphite. Graphite is indispensible for atomic energy power house Quartzite, one of the hardest rocks, used in glass making.
3. **Beauty Aids**: Steatite is used for making talcum powder and other such beauty aids.
4. **Asbestos** is fire resistant.
5. **Garnet**: It is a precious stone. It is used for making abrasives.

4. Rock Cycle

Rock cycle is the intimate relationship and mutual interdependence between the three types of rocks—igneous, sedimentary and metamorphic. The change of one type of rock into another type under different conditions is known as the rock cycle.

In the cycle of rock change, the materials of the lithosphere are constantly being formed and transformed in both their physical and mineral composition. The rock cycle has neither a beginning nor an end.

There are two environments for the working of a rock cycle, such as:

(a) a surface environment of low temperature and pressure
(b) a deep environment of high temperature and pressure.

At the surface of the Earth, the igneous rocks are exposed to the agents of weathering and erosion. They are then broken and deposited in basins or depressions. Here the sediments are compressed and cemented into sedimentary rocks.

The leftover igneous rocks and the newly created sedimentary rocks are likely to change into metamorphic rocks due to heat and pressure in course of time.

The formation of sedimentary rock on the Earth's surface and its conversion into metamorphic rock takes place within the crust of the Earth.

The sedimentary rocks may be buried again and may melt to form the igneous rocks.

In the rock cycle, the matter of the Earth's crust is not lost. The cycle of rock change has been active since our planet became a solid.

The loops in the cycle of rock change are powered by two main sources of energy such as:

- the heat inside the Earth, which can melt the existing rocks; and
- the solar energy responsible for weathering and erosion, and finally converting them into sedimentary rocks.

Throughout the geological period of millions of years, the mineral matter of the Earth has been changing due to the working of the rock cycle.

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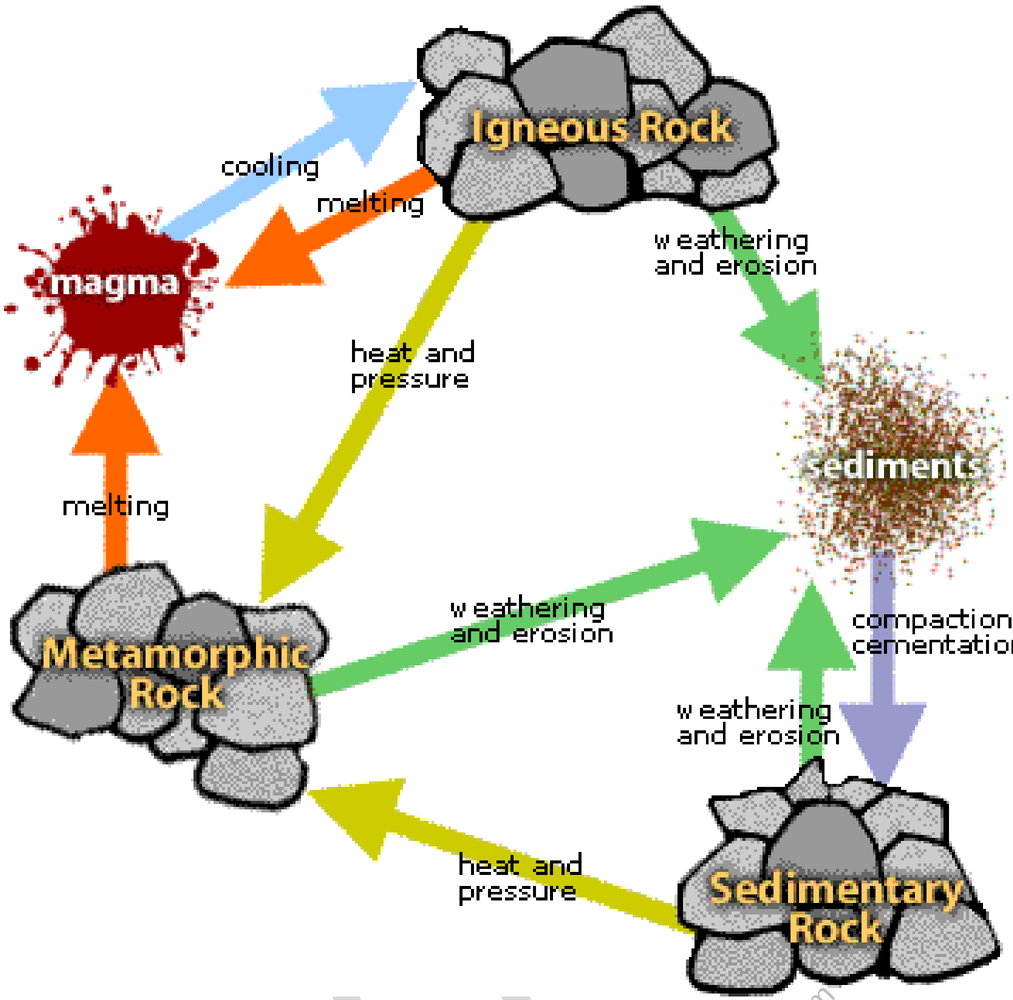


Student Notes:

LANDFORMS AND THEIR EVOLUTION

Contents

Student Notes:

Student Notes:

1. Introduction

The surface of the earth is very uneven and never perfectly flat. It has highlands and lowlands; slopes of varying types -steep, gentle, long and gradual and some very abrupt features. There are depressions and cracks of different shapes and sizes. There are also large areas of almost flat land. Some are rocky, some sandy while the others are covered with soil and vegetation. **These different land features that form a part of the larger landscapes (large tracts of the earth's surface) are known as landforms**. Each landform has a typical physical shape, size and material make up.

2. Landform and Landscape

A landscape is the general shape of the land surface. Each landscape has its own geologic structure and topographic relief. Topographic relief is the change of elevation between the highest and the lowest places. Landscapes include a variety of topographic features related to the processes that shaped the land surface. A landform is a single feature of a landscape such as mountain, valley or a river system. Hence, several related landforms together make up landscapes.

Topography refers to the elevation and relief of the Earth's surface.

Landforms are the topographic features on the Earth's surface.

Geomorphology is the study of earth surface processes and landforms.

3. Causes

The landforms on the Earth's surface have been created and developed by two types of forces—the tectonic forces and the gradational forces(weathering etc.). The tectonic forces originate from within the Earth and create irregularities on the surface of the Earth. The gradational forces originate from outside the Earth and work to modify and smoothen the irregularities created by the tectonic forces. The work of these two types of forces develops the relief features or landforms on the surface of the Earth. (Read more from Geomorphic Processes Notes).

4. Landforms and Scale: Crustal Orders of Relief

To make a systematic study of the landforms, the geographers have divided the landscape into three orders of relief.

1. The first order of relief includes the continental platforms and the ocean basins. The continental platform is the land above the sea level and the ocean basins are the land below the sea level.
2. The second order of relief includes the mountains, plateaus and plains. In the ocean basins, it includes the continental shelves, continental slopes, abyssal plains, mid-oceanic ridges, submarine canyons and trenches.
3. The third order of relief includes the mountain peaks, cliffs, hills, spurs, sand dunes, valleys, gorges, caves, beaches, etc.

5. Evolution of Landform

Every landform has a beginning. Landforms once formed may change in their shape, size and nature slowly or fast due to continued action of geomorphic processes and agents.

Due to changes in climatic conditions and vertical or horizontal movements of land- masses, either the intensity of processes or the processes themselves might change leading to new modifications in the landforms. Evolution here implies stages of transformation of either a part of the earth's surface from one landform into another or transformation of individual landforms after they are once formed. That means, each and every landform has a history of development and changes through time. A landmass passes through stages of development somewhat comparable to the stages of life — **youth, mature and old age.**

The evolutionary history of the continually changing surface of the earth **is essential to be understood in order to use it effectively without disturbing its balance and diminishing its potential for the future**. Geomorphology deals with the reconstruction of the history of the surface of the earth through a study of its forms, the materials of which it is made up of and the processes that shape it.

6. Landform Classification[1]

The genetic landform classification system groups landforms by the dominant set of geomorphic processes responsible for their formation. This includes the following processes and associated landforms:

1. Tectonic Landforms
2. Extrusive Igneous Landforms
3. Intrusive Igneous Landforms
4. Fluvial Landforms
5. Karst Landforms
6. Aeolian Landforms
7. Coastal Landforms
8. Ocean Floor Topography
9. Glacial Landforms

Within each of these, the resulting landforms are a product of either constructive and destructive processes or a combination of both. Landforms are also influenced by other agents or processes including time, climate, and human activity.

7. Fluvial Landforms (Latin: Fluvius=River)

In humid regions, which receive heavy rainfall running water is considered the most important of the geomorphic agents in bringing about the degradation of the land. The landforms either carved out (due to erosion) or built up (due to deposition) by running water are called Fluvial Landforms (both erosional and depositional) and the running waters which shape them are called fluvial process.

Fluvial processes involve both the overland flow of water down the slope, and stream flow in which water moves in a channel along a valley bottom.

7.1. Action of a River/Stream

The work of a stream includes erosion, transportation and deposition. These activities go on simultaneously in all stream channels.

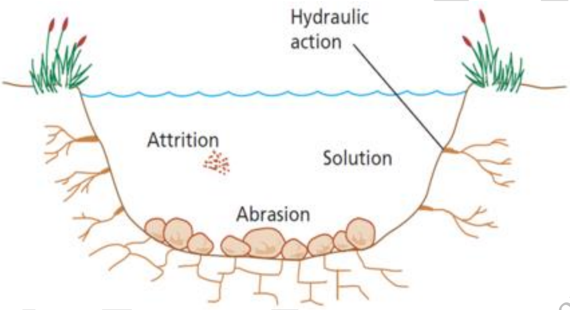
[1] Notes 1: We will discuss only important Landforms here. 2. Too many new terms are introduced in this chapter so do not try to memorise all landforms in first go. 3. Observe the diagram before reading the description. 4. Some landforms are discussed in other notes. 5. Landform are generally not asked in mains but could be asked due to changed syllabus. Moreover, understanding of landforms is needed to understand Indian phiyography correctly. Understanding of Landform also assist us in International relations (Geostrategy, Culture), Economic, Science and Tech. etc. 6. Notes are little bigger due to inclusion of more diagrams)

Student Notes:

7.1.1. Erosion

It is the removal of rock or soil. Stream erosion takes place through four processes – hydraulic action, abrasion, attrition and solution

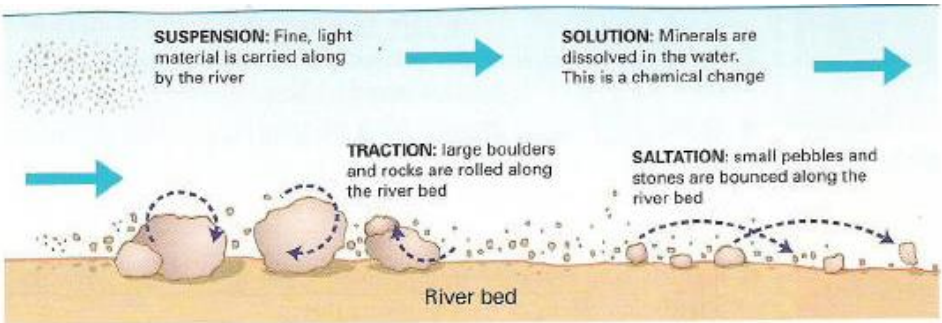
- **Solution or Corrosion-** This is the chemical action of river water. The acids in the water slowly dissolve the bed and the banks. This occurs in streams running through rocks such as chalk and limestone.
- **Abrasion or Corrasion-** As the rock particles bounce, scrape and drag along the bottom and sides of the river, they break off additional rock fragments. This form of erosion is called corrasion. This is the mechanical grinding of the rivers against the banks and bed of the river. The erosional mechanism of abrasion operation in two ways
  (i) Lateral Corrasion: This is sideways erosion which widens the river valley.
  (ii) Vertical Corrasion: This is the downward erosion which deepens the river valley.
- **Attrition-** is the mechanical tear and wear of the erosional tools in themselves. The boulders, cobbles, pebbles etc. while moving with water collide against each other and thus are fragmented into smaller and finer pieces in the transit.
- **Hydraulic Action-** involves the breakdown of the rocks of valley sides due to the impact of water currents of channel. In fact, hydraulic action is the mechanical loosening and removal of materials of rock by water alone. No load or material is involved in this process.



7.1.2. Transportation

River carries rock particles from one place to another. This activity is known as transportation of load by a river. The load is transported in four ways.

- **Traction -**The heavier and larger rock fragments like gravel, pebbles etc. are forced by the flow of river to roll along its bed. These fragments can be seen rolling, slipping, bumping and being dragged. This process is known as traction and the load is called traction load.
- **Saltation-**Some of the fragments of the rocks move along the bed of a stream by jumping or bouncing continuously. This process is called saltation.
- **Suspension-**The holding-up of small particles like sand, silt and mud by the water as the stream flows is called suspension.
- **Solution-**Some parts of rock fragments are dissolved in the river water and are thus transported.



Student Notes:

7.1.3. Deposition

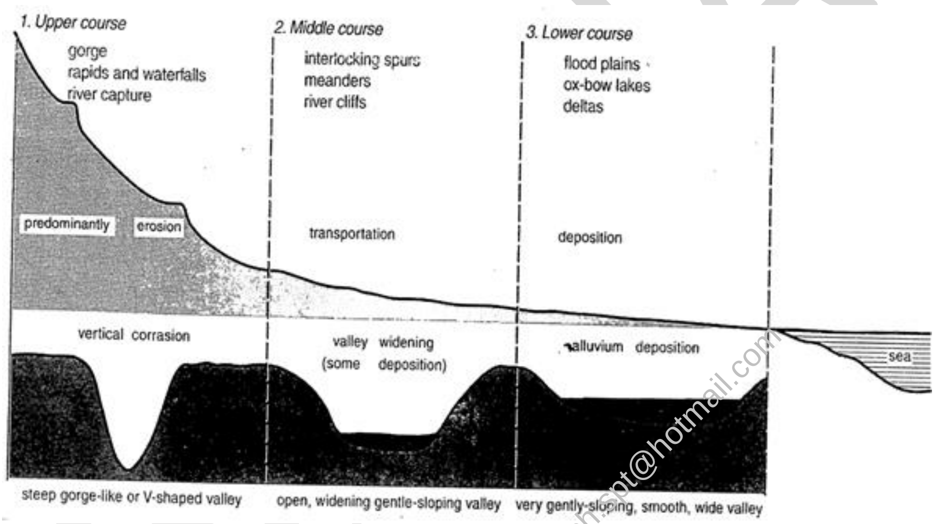
When the stream comes down from hills to plain area, its slope becomes gentle. This reduces the energy of the stream. The decrease in energy hampers transportation; as a result part of its load starts settling down. This activity is known as deposition. The larger particles, such as boulders and pebbles, are deposited first and the finest particles of silt are the last to be deposited. Deposition takes place usually in **plains and low lying areas**. When the river joins a lake or sea, the whole of its load is deposited.

7.1.3.1. Development of a River Valley

The erosional and depositional land features produced and modified by the action of running water may be better understood if we note the stages through which a stream passes from its source to its mouth. The source of a river may lie in a mountainous region and the mouth may meet the sea or lake. The whole path followed by a river is called its course or its valley.

The course of a river is divided into three sections:

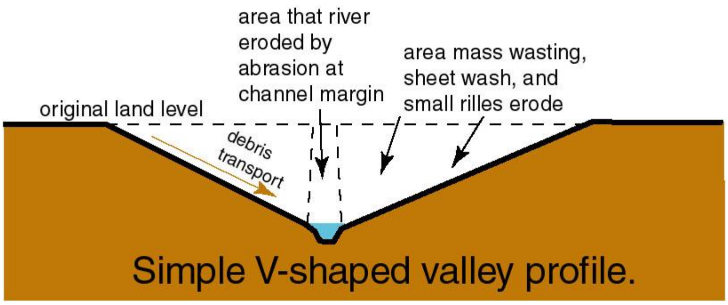
1. The upper course or the stage of youth
2. The middle course or the stage of maturity
3. The lower course or the stage of old age.



The Upper, Middle and Lower Courses of River

7.1.3.1.1. The Upper Course

The upper course begins from source of the river in hilly or mountainous areas. The river tumbles down the steep slopes and as a result, its velocity and eroding power are at their maximum. Consequently, valley deepening assumes its greatest importance at this stage. Normally, weathering also plays its part on the new surfaces exposed along the banks of the stream. The weathered rock material is carried into the stream partly through the action of gravity and partly by rain water flowing into the river. Weathering helps in widening a valley at the top giving it a typical 'V' shaped cross section. Such valleys are known as 'V' shaped valleys.



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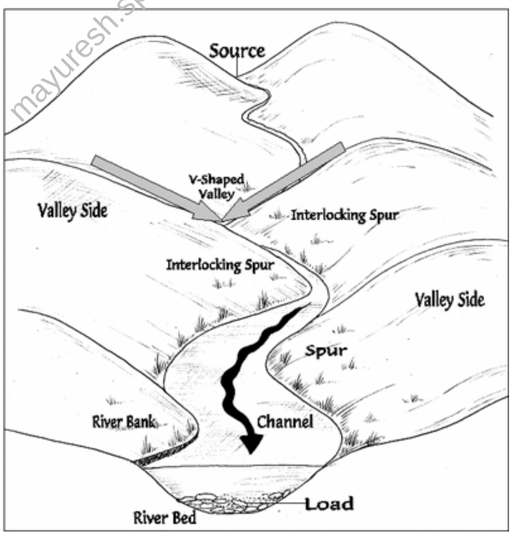
- If the bed rock is hard and resistant, the widening of the valley at its top may not take place and the down cutting process of a vigorous river may lead to the formation of a **gorge** i.e. a river valley with almost vertical sides. George generally develops between pairs of escarpments or cliffs. In India, deep gorges have been cut by the Brahmaputra and the Indus in the Himalayas. Deep gorges also develop in limestone regions and in rocks lying in dry climates.

The Valley of Kaveri river near Hogenekal, Dharmapuri district, Tamilnadu in the form of gorge

Grand Canyon of the river Colorado in U.S.A.



interlocking spurs

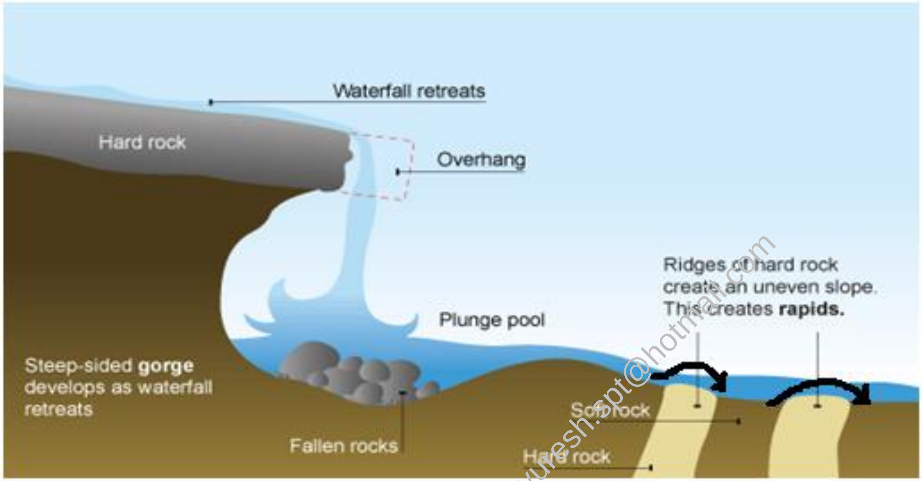
- The narrow and very deep gorge with vertical walls is known as 'I' shaped valley or **canyon**. A canyon is **very deep gorge with steep sides running for hundreds of kilometers**, e.g. Grand Canyon of the river Colorado in U.S.A.
- As the river flows through the valley it is forced to swing from side to side around more resistant rock outcrops (spurs). As there is little energy for lateral erosion, the river continues to cut down vertically flowing between spurs of higher land creating **interlocking spurs**.

Some of the others features that are developed in the upper course of a river include rapids, cataracts, cascades, waterfalls, potholes and plunge-pool.

7.1.3.1.1.1. Waterfalls, Rapids and cataracts

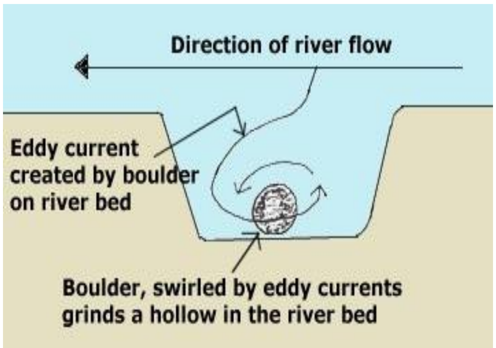
Waterfalls develop when a layer of erosion-resistant rock lies across a streams course. The less resistant rock on the downstream side is more easily eroded than the resistant rock. The river bed is thus steepened where the two rocks meet and a waterfall develops. The great force of falling water in a waterfall makes **hydraulic action** effective at its base. The blocks of rocks are broken into smaller boulders by **attrition** as they collide against each other. The base is further eroded by **abrasion** to create deep **plunge pools** beneath.

Rapids are formed due to unequal resistance of hard and soft rocks traversed by a river, the outcrop of a band of hard rock may cause a river to 'jump' or 'fall' downstream. Similar falls of greater dimensions are also referred to as cataracts. These interrupt smooth navigation.



7.1.3.1.1.2. Pot Holes

River potholes can be created when larger pieces of load that the river cannot remove by traction are swirled around by eddy currents. An eddy current is where the water turns round on itself. The river is not strong enough here to pull the large boulder (as in the diagram,) the obstruction creates a swirling motion in the water. Eventually, the boulder creates a pothole, by abrasion on the river bed.



7.1.3.1.2. The Middle Course

In the middle course, lateral corrasion tends to replace vertical corrasion. Active erosion of the banks widens the ‘V’ shaped valley and result in formation of 'U' shaped valley.

In middle valley course river often develops a winding course. Even a minor obstacles force a river to swing in loops to go round the obstacles. These loops are called **meanders. Meander is not a landform but is only a type of channel pattern.** The formation of meanders is due to both deposition and erosion and meanders gradually migrate downstream. The force of the water **erodes** and undercuts the river bank on the **outside** of the bend where water flow has most energy due to decreased friction. On the **inside** of the bend, where the river flow is slower, material is **deposited**, as there is more friction. Thus river Meanders refer to the bends of longitudinal courses of the rivers.

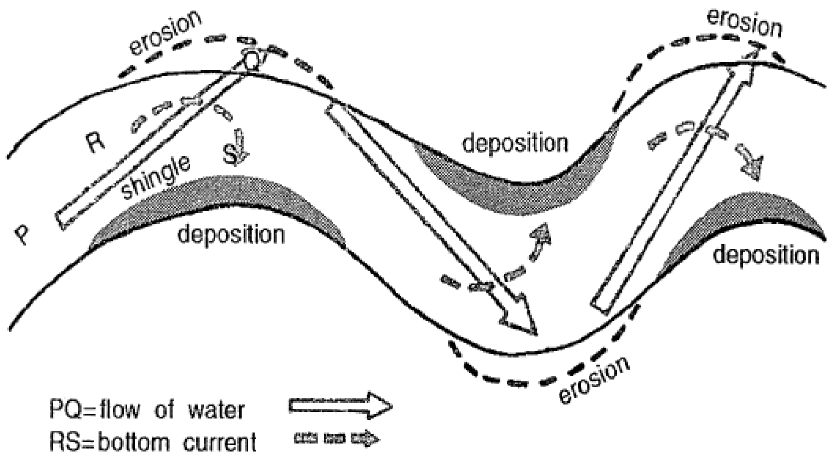
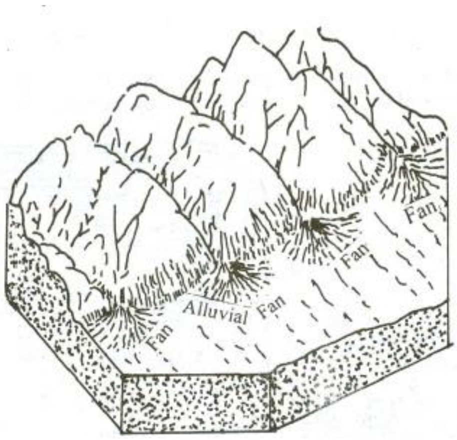


Fig: Development of a meander.

In the middle course the volume of water increases with the confluence of many tributaries and this increases the river’s load. Thus work of the river is predominantly transportation with some deposition. Rivers which sweep down from steep mountain valleys to a comparatively level land drop their-loads of coarse sand and gravels as there is sudden decrease in velocity.

The load deposited generally assumes a fan like shape, hence it is called an **alluvial fan**. Sometimes several fans made by neighbouring streams often unite to form a continuous plain known as a **piedmont alluvial plain**, so called because it lies at the foot of the mountain.

Figure 7.4: An alluvial fan deposited by a hill stream on the way to Amarnath, Jammu and Kashmir



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7.1.3.1.3. The Lower Course

In the lower course, the river moving downstream across a broad, level plain is heavy with debris brought down from the upper and middle courses. Vertical corrasion has almost ceased, the lateral corrasion still goes on to erode its banks further. The work of the river is mainly deposition in the lower course.

Many tributaries join the river and the volume of water increases, coarse materials are dropped and the fine silt is carried down towards the mouth of the river. Large sheets of material are deposited on the level bed and the river splits into a maze of channels. Such a stream is called a **braided stream.**

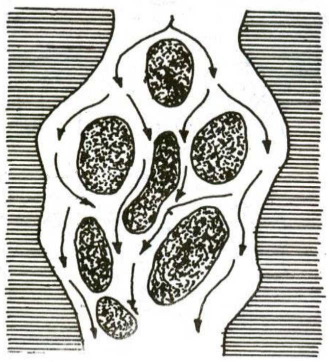
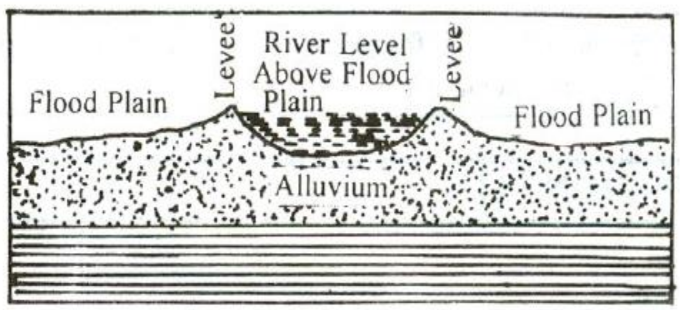


Diagram showing Braided stream

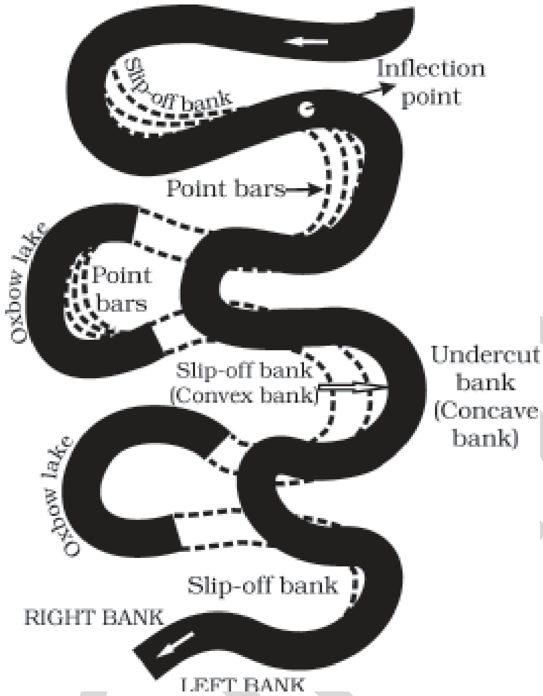


In lower course large quantity of sediment is carried by river. During annual floods, these sediments are spread over the low lying adjacent areas. A layer of sediments is thus deposited during each flood gradually building up a **fertile flood plain.**

A raised ridge of coarse material is also formed along each bank of the river due to deposition. Such ridges are called **levees**. They are high nearer the banks and slope gently away from the river. When rivers shift laterally, a series of natural levees can form.

Point bars are also known as *meander bars*. They are found on the convex side of meanders of large rivers and are sediments deposited in a linear fashion by flowing waters along the bank. They are almost uniform in profile and in width and contain mixed sizes of sediments. Rivers build a series of them depending upon the water flow and supply of sediment. As the rivers build the point bars on the convex side, the bank on the concave side will erode actively and these zones are referred as cut bank.

In the lower course of the river, meanders become much more pronounced. The outer bank or concave bank is so rapidly eroded that the meander becomes almost a complete circle. A time comes when the river cuts through the narrow neck of the loop. The meander, now cut off from the main stream, takes the form of an **oxbow lake.** When the curvature of the meander loops is so accentuated due to lateral erosion, the meander loop become almost circular and the two ends of meander loops come closer, consequently, the streams straightness their coarses and meander loops are abandoned to form ox-bow lakes. This lake gradually, turning into swamps disappears in course of time. Numerous such partially or fully filled oxbow lakes are marked at short distance from the present course of river like the Ganga.



Upon entering a lake or a sea, the river deposits all the load at its mouth giving rise to the formation of a delta .**Delta** is a triangular relief features with its apex pointing up stream and is marked as a fan-shaped area of fine alluvium. Some deltas are extremely large. The Ganga-Brahmaputra Delta is the largest delta in the world. The following conditions favour the formation of deltas:

1. active vertical and lateral erosion in the upper course of the river to supply large amount of sediments,
2. tideless, sheltered coast;
3. shallow sea, adjoining the delta and
4. no strong current at the river mouth which may wash away the sediments.

Due to the obstruction caused by the deposited alluvium, the river discharge its water through several channels which are called **distributaries.** Some rivers emptying into sea have no deltas but instead they have the shape of a gradually widening mouth cutting deep inland. Such a mouth is called **estuary**.

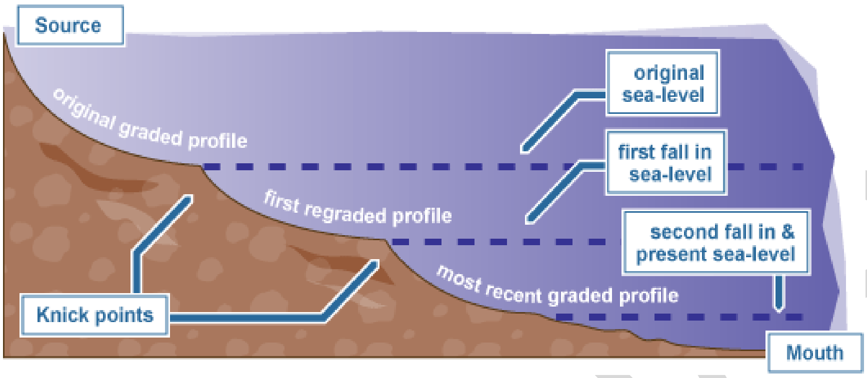
The formation of estuaries is due to the **scouring action of tides and currents**. But in most of the cases the original cause is the subsidence of the earth's crust in the area of the outlet. The two west flowing rivers of India, the Narmada and the Tapi do not form deltas. They form estuaries when they join the Arabian Sea.

7.2. River rejuvenation

Rejuvenation occurs when there is either a fall in sea level relative to the level of the land or a rise of the land relative to the sea. This enables a river to renew its capacity to erode as its potential energy is increased. The river adjusts to its new base level, at first in its lower reaches and then progressively inland. In doing so, a number of landforms may be created: knick points, waterfalls and rapids, river terraces and incised meanders.

7.2.1. Knick point

A knick point is a sudden break or irregularity in the gradient along the long profile of a river. Some knick points are sharply defined, for example waterfalls, whereas others are barely noticeable. Although a number of factors can cause such features to occur, they are most commonly attributed to rejuvenation.

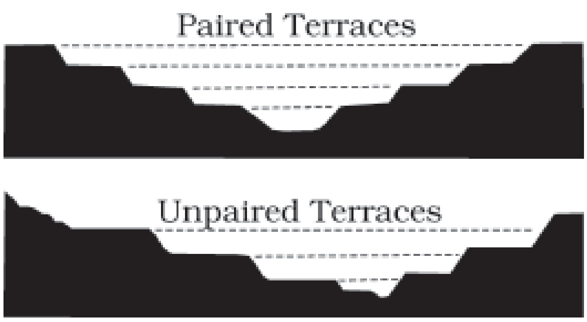


When a river is rejuvenated, adjustment to the new base level starts at the sea and gradually works its way up the river's course. The river gains renewed cutting power (in the form of vertical erosion), which encourages it to adjust its long profile. In this sense the knick point is where the old long profile joins the new.

7.2.2. River Terrace

A river terrace is remnant of a former floodplain which has been left at a higher level after rejuvenation of the river. Where a river renews its down cutting, it sinks its new channel into the former flood plain leaving the old floodplain above the level of the present river. There terraces are cut back as the new valley is widened by lateral erosion. If renewed rejuvenation takes place, the process is repeated and a new pair of terraces is formed beneath the original ones. The River Thames has created terraces in its lower course by several stages of rejuvenation. Terraces provide useful shelter from floods in a lower-course river valley, and natural route ways for roads and railways. The built-up areas of Oxford and London are mainly located along the terraces of the River Thames.

When a terrace is present only on one side of the stream and with none on the other side or one at quite a different elevation on the other side, the terraces are called non-paired terraces. Unpaired terraces are typical in areas of slow uplift of land or where the water column changes are not uniform along both the banks.



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7.2.3. Incised or Entrenched Meanders

If a rejuvenated river occupies a valley with well-developed meanders, renewed energy results in them becoming incised or deepened. The nature of the landforms created is largely a result of the rate at which vertical erosion has taken place. When incision is slow and lateral erosion is occurring, an ingrown meander may be produced. The valley becomes asymmetrical, with steep cliffs on the outer bends and more gentle slip-off slopes on the inner bends. With rapid incision, where down cutting or vertical erosion dominates, the valley is more symmetrical, with steep sides and a gorge-like appearance, These are described as entrenched meanders.

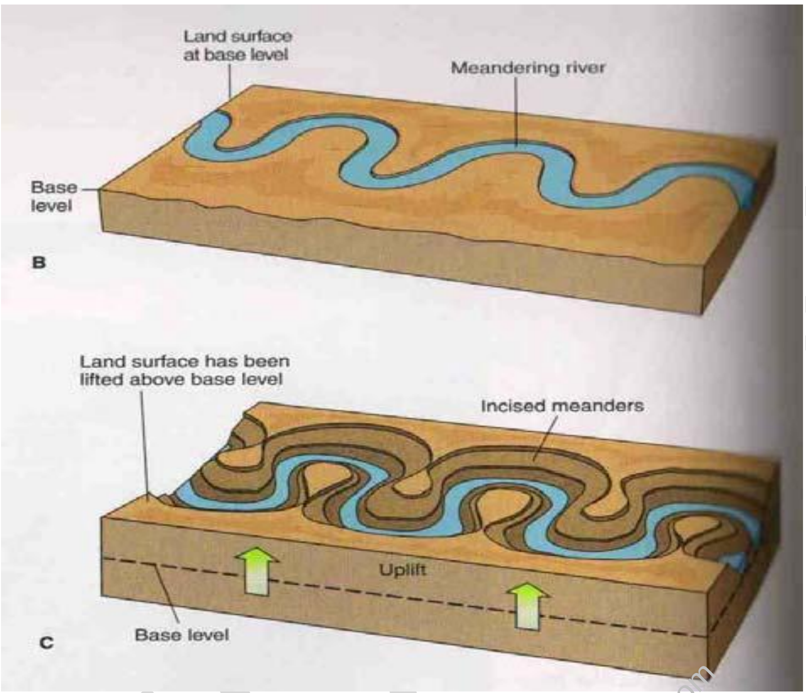

Diagram showing incised meander

7.3. Significance of work of River

All rivers undertake three closely interrelated activities erosion, transportation and deposition. Their work has therefore both advantages and disadvantages from a human point of view.

- Rapids and waterfalls interrupt the navigability of a river.
- By depositing large quantities of sediments in the lower course, the river silts up ports preventing large streamers from anchoring close to shores. Thus deltas are not suitable site for large ports.
- Many rivers flood, bursting leeves and causing damage to life and agricultural activities.
- Rivers with steep gorges and waterfalls provide natural sites for the generation of hydro electric power which further support industries through supply of energy.
- In the regions of insufficient rainfall irrigational canals support livelihood of people like Indira Gandhi canal in Rajasthan.
- The flood plains of large rivers with their thick mantles of fine silt are some of the richest agricultural areas of the world. Like delta of Ganga accounts for almost all the jute production of world.
- Fresh water fishing is important along many rivers. The organic matter brought down by the river waters provide valuable food for fishes.

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7.4. Features of Overview

	Youthful Stage – Upper course	Mature Stage – Middle Course	Old Stage –Lower Course
Characteristics	• Vertical and headward erosion • Rough channel bed • High competence, low capacity • Large gradient / slope • High turbulence • Narrow channel • Straight course	• Vertical and Lateral erosion • Wider and deeper channel • Competence decreases, capacity increases	• Deposition • Lateral erosion • High discharge & velocity • High capacity, low competence • Meandering course • Wide flood plain • Channel depth & width at maximum • Low gradient/slope
Features	v-shaped valley, waterfalls, rapids, potholes, gorges, braided streams, Interlocking spurs	Meanders, river cliffs, slip off slopes, flood plains,	Levees, deltas, point bars, sand bars, oxbow lakes, meanders, larger flood plain, raised banks

7.4.1. Erosional Landforms

- Waterfalls
- Gorges
- Rapids
- Potholes
- V-shaped valleys
- Interlocking spurs

7.4.2. Depositional Landforms

- Deltas
- Levees
- Braided Rivers

7.4.3. Erosional and Depositional Landforms

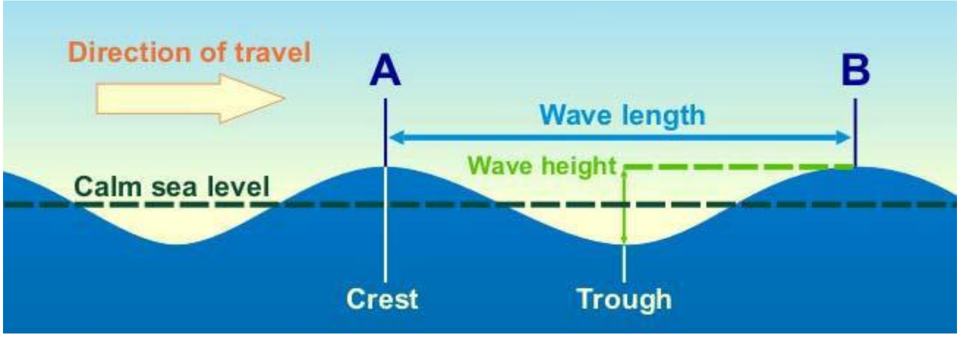
- Meanders
- Oxbow lakes
- Floodplains

8. Coastal landforms

8.1. Coastal processes: Tides, Current and Waves

Coastal processes are the most dynamic and hence most destructive. The coastline of any place is always affected by the dynamic processes operating on the coasts, such as tides, waves and current.

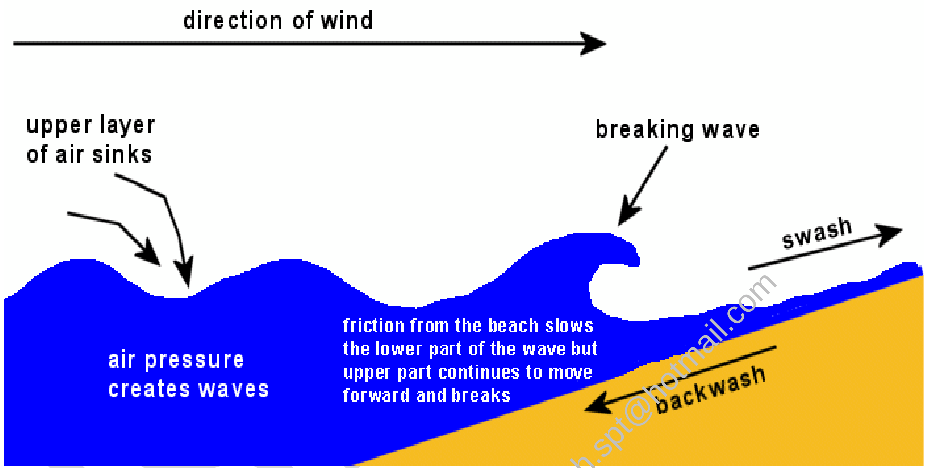
Tides and currents when come in contact with the shore have very little direct impact on the coastline. Instead, Waves are the prime agents of erosion in coastal regions. Waves are the result of transfer of energy from atmosphere to water by the wind moving over the water surface. The size of a wave is dependent upon wind velocity, wind duration and the area or distance over which the wind is traveling.



Anatomy of a wave

8.1.1. Sea Waves mechanism

Waves are most destructive during storm conditions. They exhibit a chaotic pattern at that time, with smaller waves being superimposed over larger waves. The destruction caused by combined effect of those waves is very huge. When these waves approach shallow areas near the coast, they experience rapid reduction in speed. The result is curling of the crest and eventual breaking of the wave. The zone of breaking of waves is called the ***surf zone.*** When a wave breaks, the water from it runs up the beach. This is called the ***swash***. The movement of water back down the beach to the sea is called the ***backwash.***



Surf Zone: Swash and Backwash

Coastal landforms are of two types erosional landform and depositional landform.

8.2. Coastal erosion

Coastal erosion is the wearing away and breaking up of rock along the coast. Sea waves play a prominent role in coastal erosion. The rate of marine erosion depends on the nature of rock, the extent of rock exposure to the sea, the effect of tides and currents, and human interference.

8.3. Erosional Features

8.3.1. Cliffs and wave-cut-platforms

A rock rising vertically above sea water with steep slope is called cliff. It is formed because maximum impact of the sea waves is observed on the lower part of the coastal rocks and consequently the lower part of the rocks is eroded more rapidly than the upper part. In India a number of sea cliffs are found along the Konkan Coast of India.

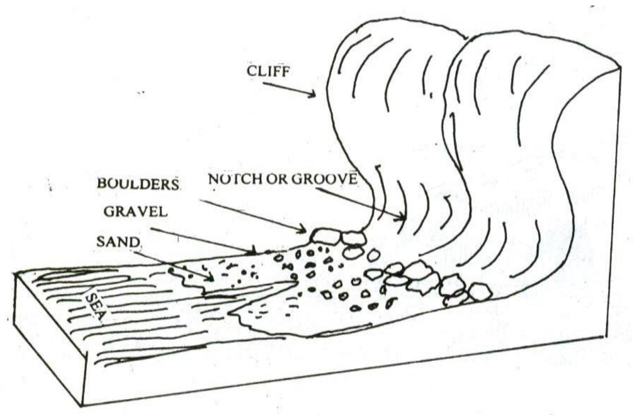


Figure No. 3- Cliff

As the cliff retreats, a new landform is formed. This is a ***wave-cut-platform***. It is a gentle sloping rock cut flat surface. It is created at the bottom of the cliff face. It is not a smooth platform of rock, rather it consists of ridges and grooves. The basic reason for the formation of a wave-cut-platform is the recession of the cliff.

8.3.2. Capes and bays

Capes and bays are features of irregular coastline. They are formed where hard rocks like granite and limestone occur in alternating bands with softer rocks like sand and clay.

- The softer rocks are eroded and converted into **inlets, coves and bays**.
- The harder rocks resist erosion and persist as **headlands or capes**.

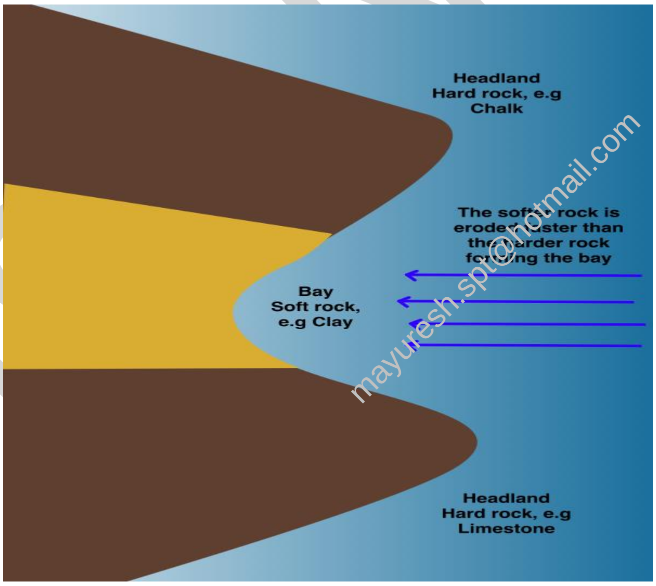


Figure No. 4- Formation of Headlands and Bays

8.3.3. Cave, Arch and Stack

The processes of erosion by waves particularly hydraulic power and corrosion, convert any vertical line of weakness in rocks into ***caves.*** However, the rock needs to be relatively hard or resistant otherwise it will collapse before the cave is formed.

If the headland is subjected to erosion from two sides, the caves developing on either sides of the headland join to form a ***natural arch*** or ***sea arch***. With time, continued erosion causes the arch to collapse, leaving an isolated vertical column of the rock, known as a ***stack***, in front of

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the cliff. In due course of time, the stack also gets eroded by the action of waves and it ends up in the form of a ***stump***.

Continual erosion by waves in caves led to-   arch → stack → stump

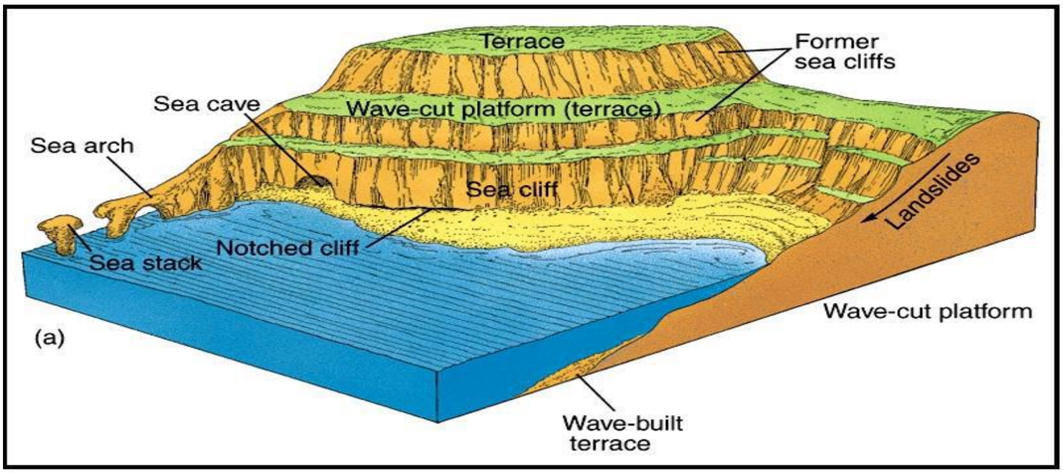

Figure No. 5-Coastal Erosional Features

8.3.4. Blow holes and Geos

Hole on the roof of the cave is known as blow hole. When the lines of weakness occur on the roof of a cave, hydraulic action of waves leads to the collapse of joint blocks from the roof and leads to the development of a hole on the roof.

The enlargement of blow holes and continued action of waves weakens the cave roof. When the roof collapses, a long narrow inlet, or creek, develops. Such deep and long creeks are called **geos**

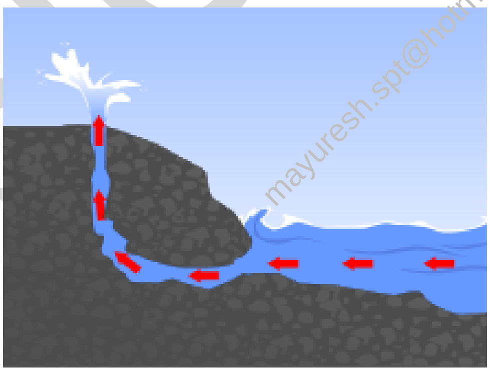

Figure No. 6- blow holes

8.4. Depositional Features

The sea waves also transport the eroded materials and deposit these at other places. Landforms resulting from deposition include platforms, beaches, bars & tombolos .

8.4.1. Wave-Built Platform or Terrace

It is a terrace formed by the deposition of sediments derived from the erosion of cliffs or from the continued abrasion of a cliff by the action of waves.

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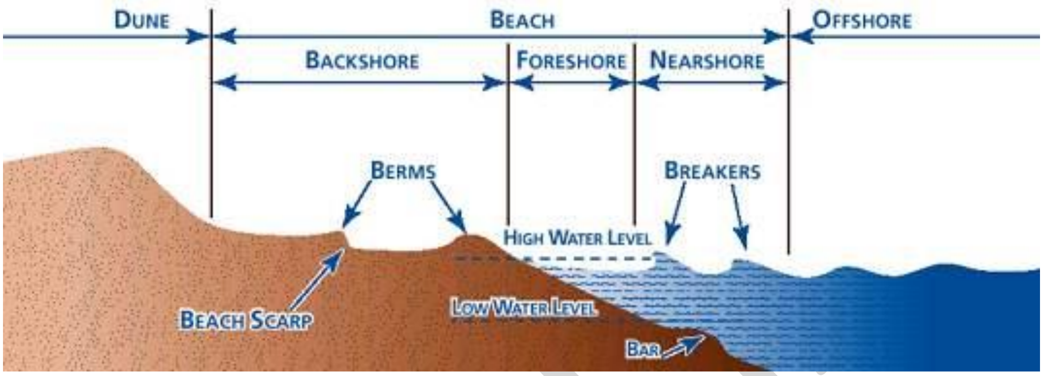
8.4.2. Beaches

Beaches are the most familiar of all the coastal landforms. They are the main feature of deposition found along the coast. They consist of all the material (sand etc.) built up between the high and low tide mark (High tide is highest level of tide while low tide is lowest level of tide). There are a number of different sources of beach material. Rivers are the main source as fine mud and gravel are deposited at the mouth of a river. Other sources of beach material include constructive waves (bringing material up the beach from the sea) and cliff erosion. Beaches are temporary features. Beaches called **shingle beaches** contain excessively small pebbles and even cobbles. Marina Beach of Chennai and Kovalam Beach of Thiruvananthapuram are the famous beaches of India.

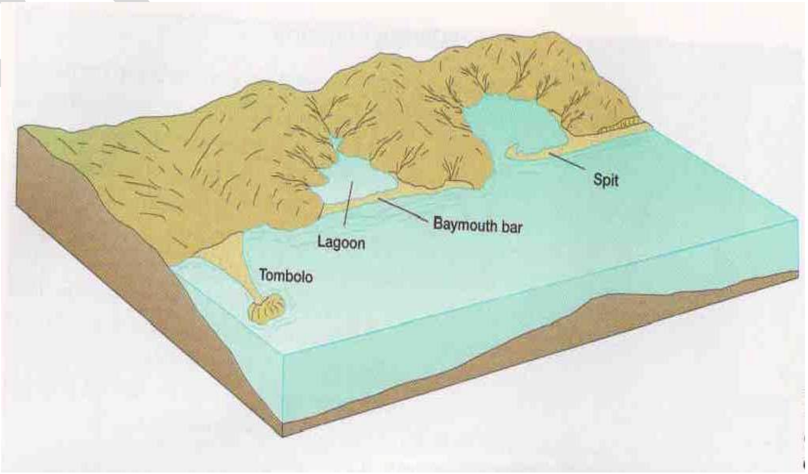


Beach and related features

8.4.3. Bars, Spits and Tombolo

These are ridges of sand, pebbles or mud.

- Bar is such ridge which has joined two headlands cutting across a bay. (see figure) .Sand bars that obtain a length of hundreds of kilometres are called **offshore bars or longshore bars**.
- Offshore bars may enclose a water body to form a **lagoon**, such as the Chilka Lake and Pulicat Lake in India. (Laggons are referred as Kayals in Kerala).
- If bars are formed in such a way that one end is linked to land and the other end projects into the sea, they are called **spits**.
- A connecting bar that joins two landmasses (mainland to island) is known as a ***tombolo***. (see figure 8)



Depositional Features along the Coast

8.5. Types of Coasts

Coastlines are divided into two basic types (1) Coastline of Submergence (2) Coastline of Emergence

8.6. Coastlines of submergence

Coastlines of **submergence** are formed in Coastal areas which have become lowered below current sea level. The cause is rise in sea level in consequence of ice melting since the last ice age. This group includes Ria, fiord, estuarine, and Dalmatian or Longitudinal coasts.

a) Ria Coasts: A ria coast is formed when a non-glaciated highland coast becomes submerged and the valleys filled with sea water. These submerged valleys are often V-shaped. This type of coast is found in north-western Spain and south-western Ireland.

b) Fiord (Fjord) Coasts: A fjord is a narrow, high-walled, and very long submerged glacial valley. Fjords are formed when a descending glacier carves a U-shaped valley into the bedrock. When these fjord are submerged fjord coast is formed.

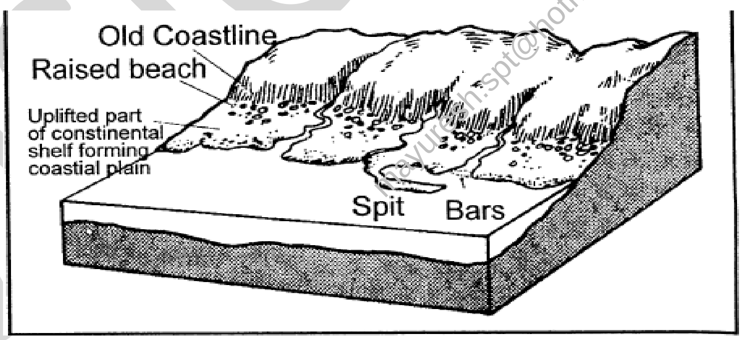
c) Dalmatian or Longitudinal Coasts: These coasts are formed when a mountain ridge running parallel to the sea coast is submerged. In this mountain ranges become chains of islands resembling patches on body of Dalmatian dog.

d) Estuarine Coast: Estuary/estuarine coasts are coasts where lowland coasts are submerged, flooding river. Their entrances are sand and silt free, Thames of Britain are the example of such type of coasts.

8.7. Coastlines of Emergence

Uplifted or **emergent coasts** are coasts where the coast has been raised(due to fall in sea level or a rising of the crust) and the ocean waves now erode a lower level.

a) **Emerged Upland Coasts:** An emerged highland coast is formed when coastal plateau lands are raised above sea level. The chief feature of an emerged upland coast is a raised beach or cliff-line which now found above the present zone of wave action. The Northern part of west coast of India is an example of an emerged upland coast.



Emergent upland coast

b) **Emerged Lowland Coasts:** An emerged lowland coast is produced by the uplift of part of the neighbouring continental shelf. The chief feature of an emerged lowland coast is spits lagoons, bars, marshes and beaches. The coasts of Kerala and Tamil Nadu are example of an emerged lowland coast.

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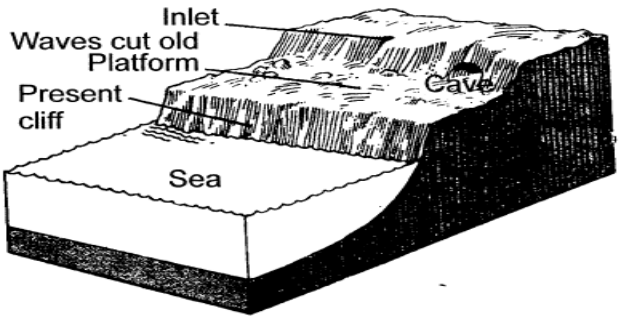


Emergent lowland coast

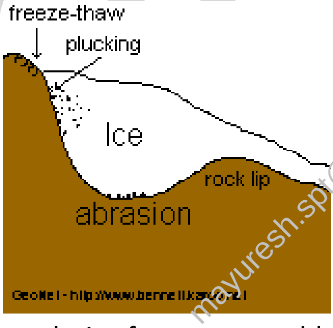
9. Glacial Landforms

A moving mass of ice and snow is called a glacier. Glaciers are formed when there is net year to year accumulation of snow, that is, when the amount of snow that falls in winter is greater than the amount that melts away in summer. Snow keeps on accumulating in layers one above the other. Its overlying pressure is applied to the underlying snow. It is so great that snow in lower layers becomes granular, hard and compact. The pressure also quickens the melting of some of the snow, which on refreezing starts turning into a granular ice. Again it is the pressure of the overlying layers which makes this solid mass of ice mobile. Thus glacier is formed through the processes of **accumulation, compaction** and **recrystallisation** of snow.

The movement of glacier is very slow and it moves from a few centimetres to a few metres in a day.

9.1. Action of Glacier

There are three main types of glacial erosion - plucking, abrasion and freeze thaw.



Plucking is when melt water from a glacier freezes around lumps of cracked and broken rock. When the ice moves downhill, rock is plucked from the back wall. Abrasion is when rock frozen to the base and the back of the glacier scrapes the bed rock. Freeze-thaw is when melt water or rain gets into cracks in the bed rock, usually the back wall. At night the water freezes, expands and causes the crack to get larger. Eventually the rock will break away.

Erosional work of glacier

Erosion by glaciers is tremendous because of friction caused by sheer weight of the ice. As a glacier moves over the land, it drags rock fragments, gravel and sand along with it. These rock fragments become efficient erosive tools. With their help glacier scrapes and scours the surface rocks with which it comes in contact. This action of glacier leaves behind scratches and grooves on rocks. Glaciers can cause significant damage to even un-weathered rocks and can reduce high mountains into low hills and plains.

9.2. The landforms created by glacial erosion

9.1.1. Cirque (or Corrie)

This is an arm chair shaped hollow found in the side of a mountain

9.1.2. Arete

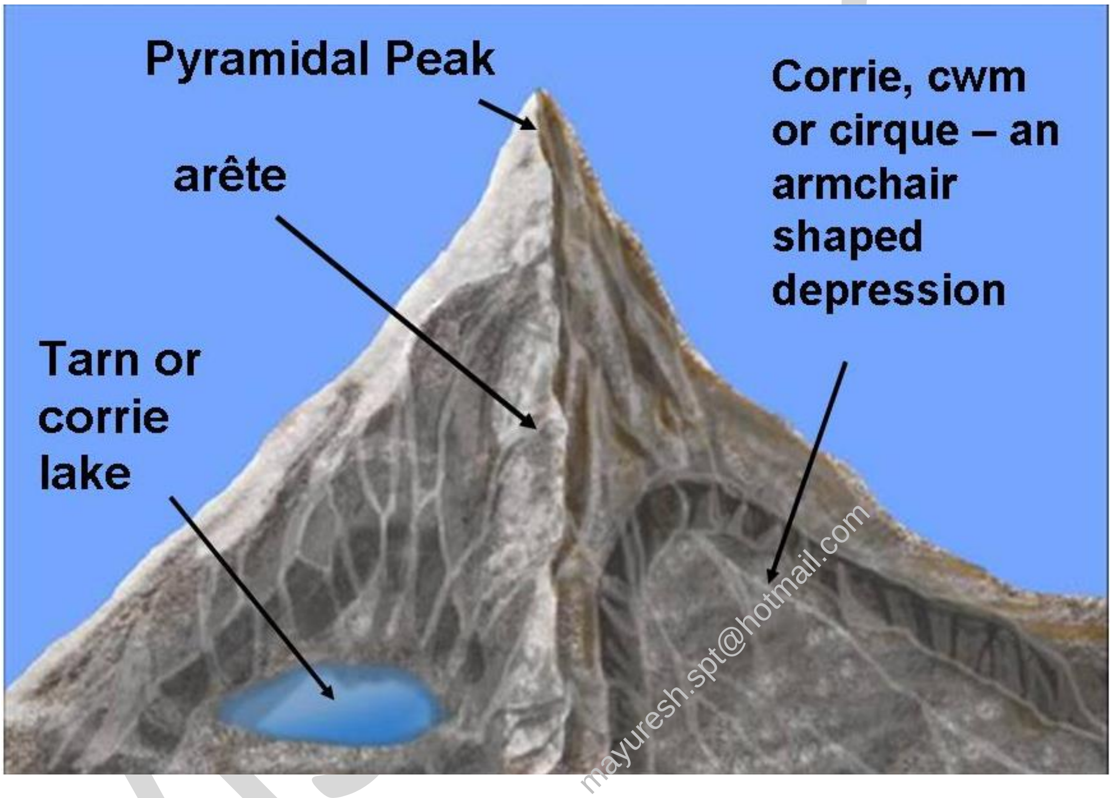
This is a narrow, knife edge ridge separating two corries

9.1.3. Pyramidal Peaks

These are formed when three or more corries form in the side of one mountain.

9.1.4. Tarn

This is a lake found in a corrie



Cirque, arete and pyramidal peak

9.1.5. Bergschrund

These form when a crevasse or wide crack opens along the headwall of a glacier; most visible in the summer when covering snow is gone.

Figure no.2- Bergschrund

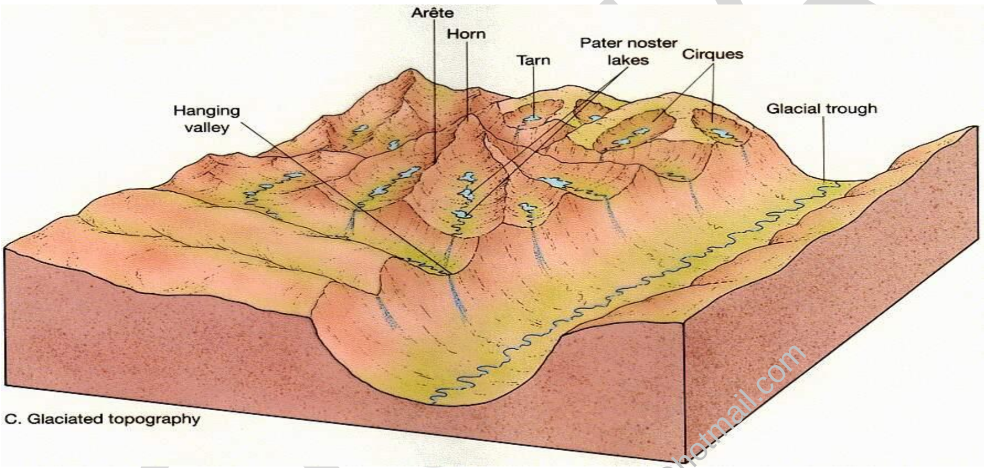
Student Notes:

9.1.6. 'U' - shaped Valley

The glacier does not carve a new valley like a river but deepens. Glacier movement widens a preexisting valley by smoothening away the irregularities. In this process the glacier broadens the sides of the valley and form a 'U' - shaped valley. Such a valley is relatively straight, has a flat floor and nearly vertical sides.

9.1.7. Hanging Valley

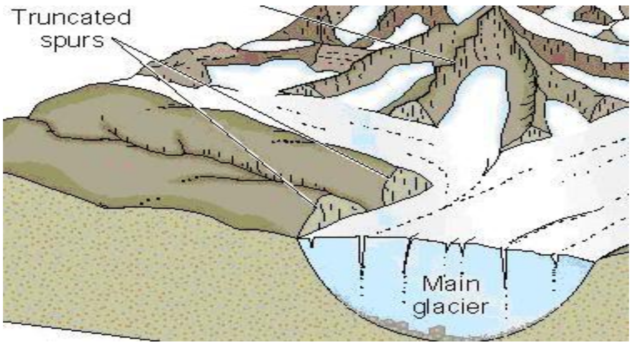
Just like tributary streams of river, there are tributary glaciers also which join the main glacier after moving over their mountainous path. These tributary glaciers like the main glaciers carve U - shaped valleys. However, they have less volume of ice than the main glaciers and thus their rate of erosion is less rapid. As a result their valleys are smaller and not as deep as that of the main glacier. Due to this difference in deepening; the valley of the tributary glacier is left at a higher level than that of the main glacier. The valley of the tributary glacier just looks like hanging downwards at the point of its confluence with the main valley. This type of a topographical feature is called a hanging valley. This feature is visible when ice has melted in both the valleys. When the ice in the hanging valley melts, a waterfall is formed at the point of confluence of this stream with the main river.



Glacial Erosional Landforms

9.1.8. Truncated spurs

In the process of carving the sides of its valley, a glacier erodes or truncates the lower ends of ridges that extended into the valley. These ridges that have triangular facets produced by glacial erosion at their lower ends are termed as **truncated spurs.**



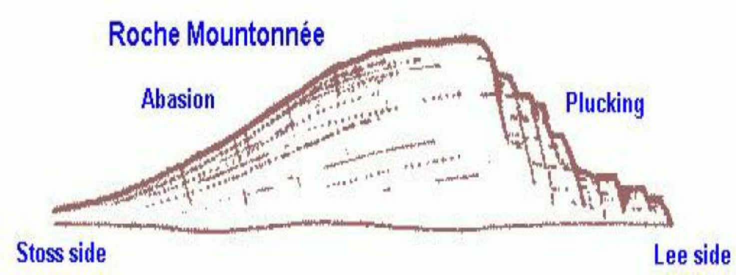
9.1.9. Paternoster lakes

A series of Tarns lakes, resembling a string of prayer beads, are known as **paternoster lakes.**

Student Notes:

9.1.10. Roche Moutonnee

A roche moutonnée is a rock hill shaped by the passage of ice to give a smooth up-ice side (stoss side) and a rough, plucked surface on the down-ice side(lee side).



Roche Moutonnee

9.2. Glacial landforms resulting from deposition

Glaciers carry along their bases the rock fragments they have scraped and plucked from the underlying bedrock. These forms the feature of glaciated lowland.

The landforms created by glacial erosion are:

9.2.1. Boulder clay or glacial till

The unassorted coarse and fine debris dropped by the melting glaciers is called glacial till.

9.2.2. Outwash deposits

Some amount of rock debris small enough to be carried by such melt-water streams is washed down and deposited. Such glacio- fluvial deposits are called *outwash deposits*. Unlike till deposits, the outwash deposits are roughly stratified and assorted.

9.2.3. Erratics

When boulders of considerable size are deposited far from their origin, they are known as **erratics**. They have been transported and deposited by a glacier.

9.2.4. Moraines

When glacial ice melts, different types of rock are laid down that have been carried along by the glacier. Piles of these deposits are called moraines.

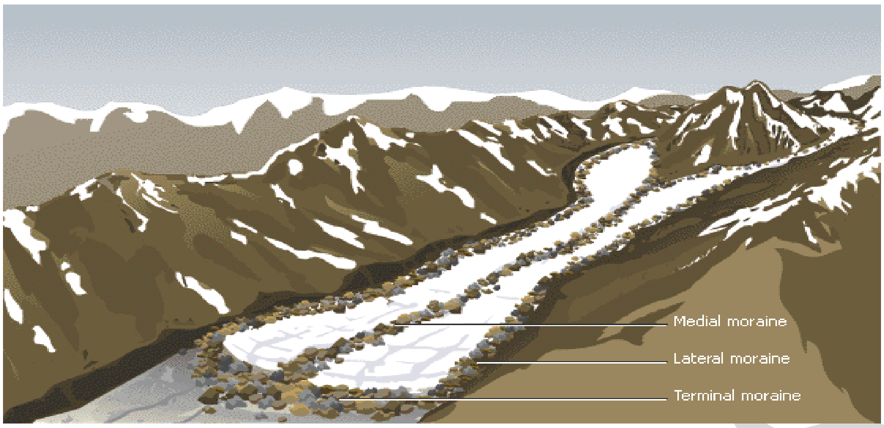
Different types of moraine

Terminal moraines are found at the terminus or the furthest (end) point reached by a glacier.

Lateral moraines are found deposited along the sides of the glacier.

Medial moraines are found at the junction between two glaciers.

Ground moraines are disorganised piles of rocks of various shapes, sizes and of differing rock types.



9.2.5. Outwash plain and Kettles

As the moraines are deposited, melting water emerges from the glaciers rapidly in the form of streams. These streams carry loads of suspended materials. As the water moves, it soon loses its velocity and load carrying capacity, and it drops most of its bed load. As a result, a broad surface of stratified drift is formed, which is called an ***outwash plain***. The basins or depressions found between the outwash plains are called ***Kettles.***

9.2.6. Kames

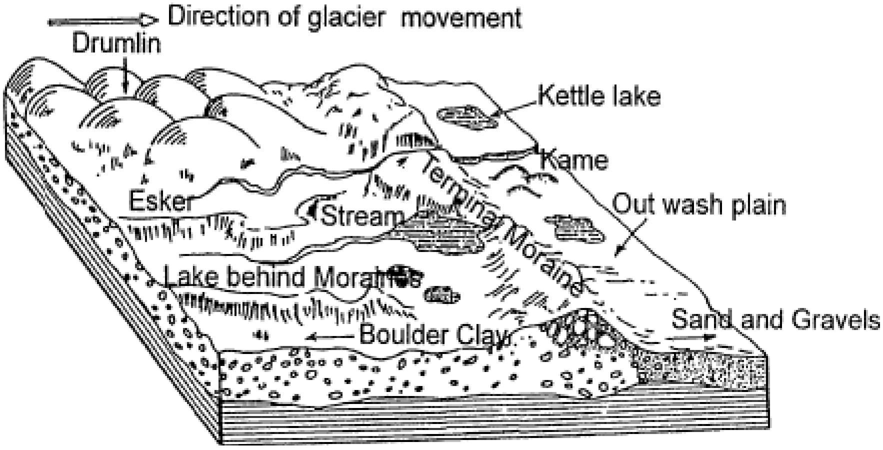
Rounded mounds/hills of fluvioglacial deposits are known as **Kames**.

9.2.7. Eskers

In glaciated areas sinuous ridges of sand and gravel are known as **eskers**. They marks the former sites of sub glacial melt water streams.

9.2.8. Drumlins

Drumlins are elongated hills of glacial deposits. They can be 1 km long and 500 metres wide, often occurring in groups. A group of drumlins is called a drumlin swarm or a basket of eggs. These would have been part of the debris that was carried along and then accumulated under the ancient glacier. The long axis of the drumlin indicates the direction in which the glacier was moving. The drumlin would have been deposited when the glacier became overloaded with sediment. However glaciologists still disagree as to exactly how they were formed.



Glacio-Fluvial Deposits

Student Notes:

10. Landform by the Action of Wind

(Also called Aeolian=Wind)

Wind is also an important agent of denudation. Wind action is mostly limited to arid and semi-arid areas of the world, where the absence of vegetation cover and the presence of extensive desolate rocks, help in erosional, transportation and depositional processes.

There is a definite pattern to the location of world deserts. Almost all the deserts are confined within the 15° to 30° north and south latitudinal belts, also known as the trade wind belts.

- Aridity is the result of lack of water, which is dependent on the mean annual rainfall.
- These areas are affected by cold currents. These cold currents ensure that there is little moisture available to condense and form clouds. The coasts of western North and South America and Africa display such conditions.
- ***Continetiality*** is also a major reason for the development of arid and semi-arid conditions. Air descending from mountainous areas warms and dries by compression, little rainfall forms and it results in aridity. Central areas of continents are also dry because air moving over landmasses does not absorb large amounts of water vapour.

About one-third of the land surface of the world can be classified as arid, semi- arid or dry. The major deserts regions of the world include the Sahara desert, Arabian Desert, Kalahari, Namib, Atacama deserts, Great Australian desert, desert of the south-west U.S.A and Mexico.

<u>The combined effect of the erosional activity of wind and water in the arid and semi-arid regions give rise to the following types of surfaces.</u>

- **Erg *(*Sandy or True Desert):** The erg in the Sahara and Saudi Arabia, and ***koum*** in Turkmenistan are the true sandy deserts. They consist of vast, almost horizontal, sand sheets or of regular dune lines, or of an undulating sand sea.
- **Stony Desert:** In a stony desert, horizontal sheets of smoothly angular gravel cover the surface. This is known as the ***reg*** in Algeria and ***serir*** in Libya and Egypt.
- **Badland:** Badland is any landscape characterised by deep dissection, ravines, gullies, and sharp- edged ridges. The name has been given after the arid area in South Dakota, U.SA.
- **Hamada or Rocky Desert**: It consists of large areas of sand and dust, with patches of bare rock. These bare rocks are perfectly smoothened and polished. This type of deserts in Sahara is known as Hamada.
- **Mountain Desert:** Some deserts are found in the highlands, mountain ranges and the plateau areas. The Ahaggar Mountain and Tibesti mountain of Sahara are examples of these deserts.

10.1. Mechanism of wind Action in deserts

Attrition: When wind borne particles roll against one another in collision they wear each other so that their sizes are greatly reduced and converted into finer materials.

Deflation: The complete blowing away of fine dust, leaving coarse and heavier materials, is known as deflation. As a result of deflation, larger hollows known as ***blow-outs*** are formed. Deflation also exposes bedrock to wind abrasion (corrasion). There are numerous ***blow-outs (deflation hollows)*** in the valley of the Nile.

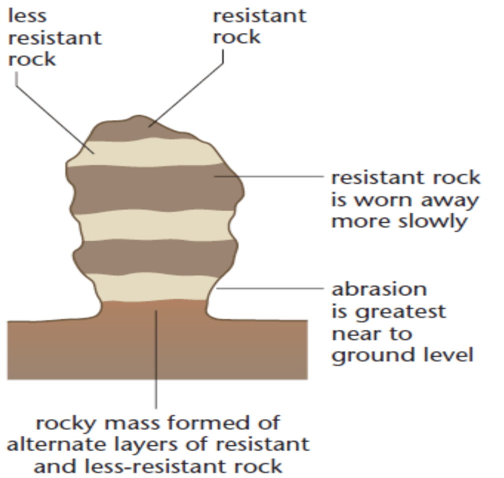
Abrasion or Corrosion: In the process of abrasion, winds pick up dust and sand and drive them with tremendous force against the rocks. In fact, in the desert and semi-desert areas, winds carry with them enormous quantities of sand, dust and small angular fragments which act as tools of erosion as they strike against the rock surfaces. By this process, the less resistant rocks are eroded and in time completely worn away, while the hard and very resistant rocks are polished and smoothed to a remarkable degree.

10.2. Erosional Landforms-Wind

10.2.1. Ventifacts or Dreikanter

These are stone that has received one or more highly polished, flattened facets as a result of erosion by windblown sand. The facets are cut in sequence and correlate with the dominant wind direction. As one surface is cut, the stone may become out of balance and may turn to expose another surface to the wind. A ventifact that has been eroded to three curved facets is called a dreikanter.

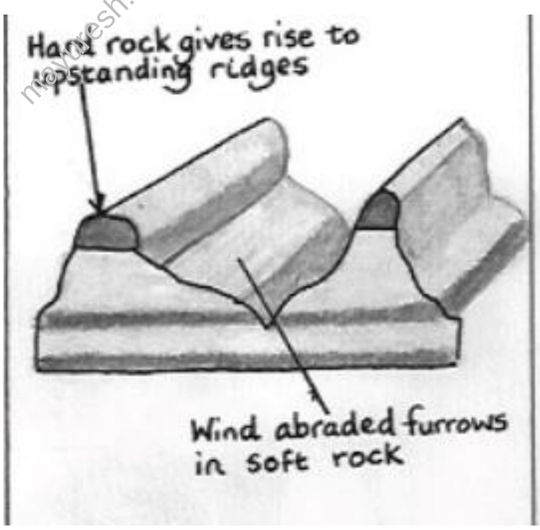
10.2.2. Ventifact



10.2.3. Rock Pedestals or Mushroom Rocks

Due to the presence of alternate layers of soft and hard rock and the effect of sand-blasting by winds on these, features with irregular edges are formed. Grooves and hollows are cut into the rock surfaces, carving them into fantastic pillars called rock pedestals.

Formation of yardangs



Formation of zeugen

Student Notes:

10.2.4. Yardangs

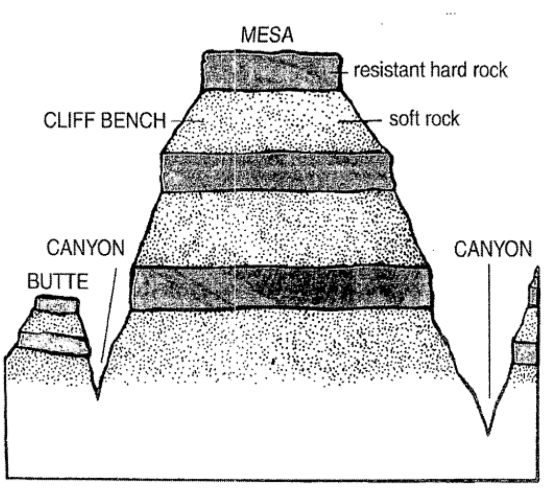
A yardang is a streamlined hill carved from bedrock or any consolidated or semi-consolidated material by the dual action of wind abrasion, dust and sand, and deflation.

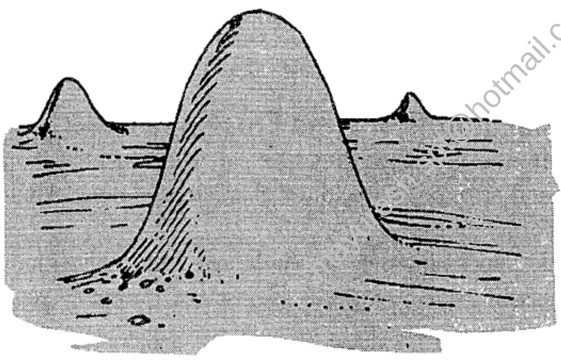
10.2.5. Zeugens

Zeugens are also formed by wind abrasion where a surface layer of hard rock is underlain by a layer of soft rock into a ridge and furrow landscape. The ridges are called zeugens which may be as high as 100 feet. Ultimately the are undercut and gradually worn away.

10.2.6. Mesas and Buttes

Mesa is a Spanish word meaning table. It is a flat, table-like landmass with a very resistant horizontal top layer and very steep sides. With continued denudation through the ages, mesas are reduced to flat-topped hills called ***buttes.***





10.2.7. Inselbergs

Inselberg is a German word for Island Mountain, has been widely adopted to describe a steep-sided hill of solid rock, rising abruptly from a plain (level ground). They are made of granite. Inselbergs in arid regions are also called ***bomhardts.***

10.3. Depositional Landforms-wind

The main depositional landforms of wind are sand dunes and loess.

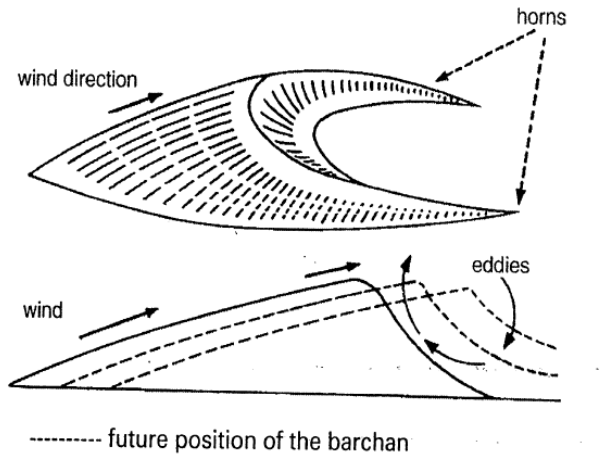
Ripple Marks: Ripple marks are small scale depositional features of sand. This pattern is produced in unconsolidated sediments by the agents of erosion-like wind. Ripples may be either longitudinal or transverse.

Sand Dunes: These are mounds or ridges of wind-blown sand. The dunes are generally mobile.

There is wide variation in their shape, size and structure. On an average, their height ranges between a few metres to 20 metres, but there are some sand dunes which are more than several hundred metres in height and 5 to 6 km in length. Dunes are most well represented in the erg desert (a broad, flat area of desert).

There are many types of sand dunes. The two most important dunes are **Barchans** and **Longitudinal** dunes, which are described in detail.

Barchans: They are crescent-shaped sand dune produced by the action of wind predominately from one direction. This type of dune possesses two "horns" that face downwind, with the steeper slope known as the slip face, facing away from the wind. They gradually migrate with the wind as a result of erosion on the windward side and deposition on the leeward side.



Longitudinal Dunes (Seif): Seif is an Arabic word, meaning sword dune. These are long, straight dunes and are parallel to the wind direction. Formed in regions where wind blows from more than one direction in a region with an abundant supply of sand.

10.3.1. Loess

Loess is fine-grained material that has been transported and deposited by the wind. The sediments come from glacial outwash plains, where glaciers deposit fine particles of silt and clay, or from desert areas that have little vegetation to anchor small particles. Prevailing wind patterns blowing across these environments can produce thick deposits of loess downwind of the area. In China such yellowish wind borne dust from the Gobi desert is called Hwangtu-the yellow earth

10.4. Fluvial Desert Landforms

Despite being a dry climate arid and semi-arid regions are also influenced by the action of water. Running water is also an important external agent for landform development in deserts. Though rare, the rainfall is intense in its effect on the lightly vegetated cover region of desert and produce abrupt runoff. This occasional rainfall in the deserts results in flash-floods. Loose gravels, sand and fine dust are swept down the hill sides. They cut deep gullies and ravines forming badland topography. The Chambal present a typical example of badland.

Some of the important landforms resulting from fluvial action in deserts are pediments, bajada, and playas.

10.4.1. Wadis

In Deserts the water flow during flash flood is so strong that it cuts the ground and carries away the soil material. This results in creation of wide channels called wadis. These remain dry for most of the times.

10.4.2. Pediments

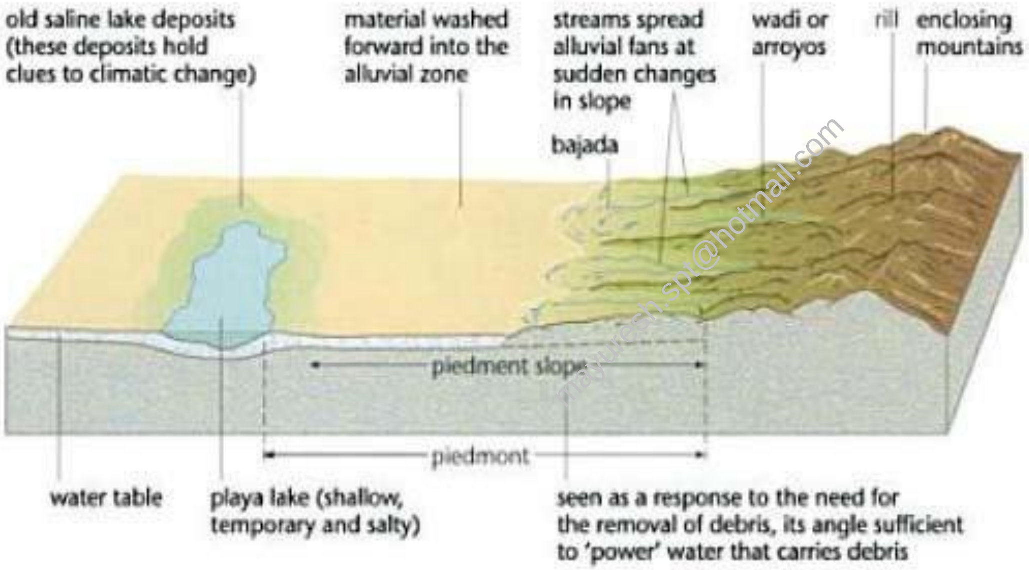
It is an erosional plain formed at the base of the surrounding mountains scraps.

10.4.3. Bahada (Bajada)

It is a depositional feature made up of alluvial material laid down by the seasonal streams. These are also known as depositional plains of desert.

10.4.4. Playas

A (shallow) playa lake may form in the central basin of a desert from abundant rainfall on rare occasions Due to evaporation and infiltration the water in these lakes are present for only a few days or weeks--the dry flat lake bed that remains is called a playa. These lakes are temporary in nature.



Desert Fluvial Landforms

11. Karst Topography

In rocks like limestones or dolomites rich in calcium carbonate the surface water as well as groundwater through the chemical process of solution and precipitation develop varieties of landforms. These two processes of solution and precipitation are active in limestones or dolomites occurring either exclusively or interbedded with other rocks. Any limestone or dolomitic region showing typical landforms produced by the action of groundwater through the processes of solution and deposition is called *Karst topography* .'Karst' word comes from the Karst region of Adriatic Sea coast in Croatia (Yugosalvia) where such formations are noticeable.

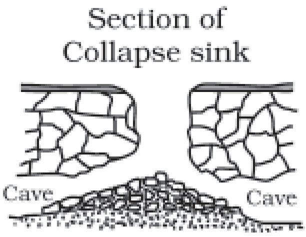
Student Notes:

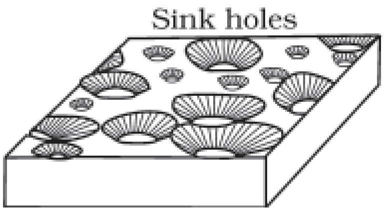
This region is made up of limestone rocks, where underground water is the most active agent of gradation.

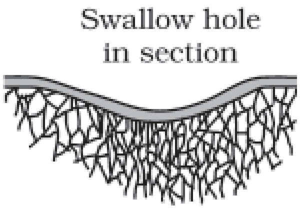
11.1. Erosional landform

11.1.1. Sink Holes, Swallow Holes, Dolines and Uvalas/valley sink

A **sinkhole** is a surface depression or hole in a region of limestone terrain. Sinkholes can range in size from a few feet or meters to over 100 meters (300 feet) deep. A sinkhole can even collapse through the roof of an underground cavern and form what's known as a collapse sinkhole



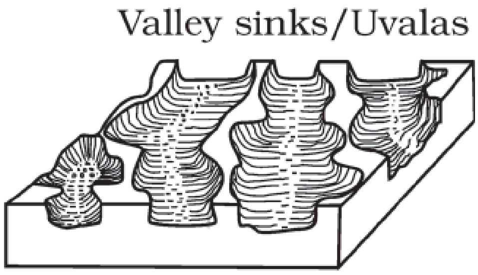




Gradual enlargement of sink holes due to continuous dissolution of limestones result in the coalescence of closely spaced sink holes into one large hole which is called **Swallow hole.**

Further enlargement of swallow holes due to continuous solution result into a larger depression which are called **dolines** in karst erosion.

Uvalas are extensive depression. Larger uvalas have been seen to cover several square kilometers, with a depth of up to 200 metres. They are formed due to coalescence of several dolines due to continuous solution and enlargement of dolines, or due to collapse of upper roof of large cavities formed underground or due to coalescence of various sink holes.



11.1.2. Lapies

It is weathered limestone surface found in karst regions and consisting of etched, fluted, and pitted rock pinnacles separated by deep grooves. This rugged surface is formed by the solution of rock along joints and areas of greater solubility by water containing carbonic and humic acids.

11.1.3. Caves

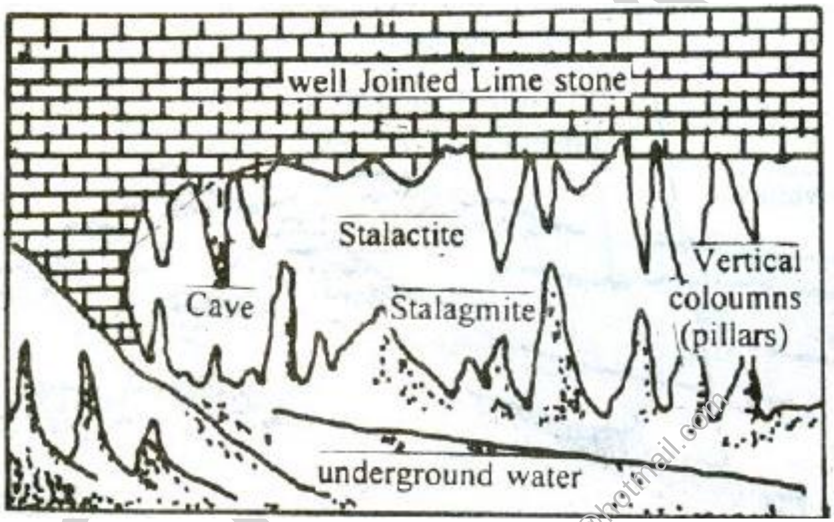
In areas where there are alternating beds of rocks (shales, sandstones, quartzites) with limestones or dolomites in between or in areas where limestones are dense, massive and occurring as thick beds, cave formation is prominent. Water percolates down either through the materials or through cracks and joints and moves horizontally along bedding planes. It is along these bedding planes that the limestone dissolves and long and narrow to wide gaps called caves result. There can be a maze of caves at different elevations depending upon the limestone beds and intervening rocks. Caves normally have an opening through which cave streams are discharged. Caves having openings at both the ends are called tunnels.

11.2. Depositional Landforms

11.2.1. Stalactites and Stalagmites

They are the major depositional features formed in the caverns in limestone regions. The water containing limestone in solution, seeps through the roofs of the caverns in the form of a continuous chain of drops. A portion of the water dropping from the ceiling gets evaporated and a small deposit of limestone is left behind on the roof. This process continues and deposit of limestone grows downwards like pillars. These forms are called **stalactites**.

When the remaining portion of the water dropping from the roof of the cavern falls on the floor, a part of it is again evaporated and a small deposit of limestone is left behind. This deposit grows upward from the floor of the cavern. These type of depositional features are called **stalagmites**. As the process grows, both stalactite and stalagmite often join together to form **vertical columns and pillars** in the caverns.



12. Economic significance of karst regions

- Karst regions are often barren. The porosity of the rocks and the absence of surface drainage makes vegetation growth difficult. Therefore, these regions support short turf and poor grasses.
- However, limestone vegetation in tropical regions is luxuriant because of all the year round rainfall.
- Lead is the only mineral of importance in karst region. Lead occurs in veins in associations with limestone.
- In addition to this, Limestone is used as building materials or quarried for the cement industry.

Student Notes:

INDIA: PHYSICAL FORMATION, PHYSIOGRAPHY, DRAINAGE, STRUCTURE AND RELIEF AND BASICS OF SOILS

Contents

Student Notes:

Student Notes:

1. India Location

India is a vast country lying entirely in the Northern hemisphere. The main land extends between latitudes 8°4'N and 37°6'N and longitudes 68°7'E and 97°25'E (figure 1). The Tropic of Cancer (23° 30'N) divides the country into almost two equal parts (figure 2). The southern part of the country lies within the tropics and the northern part lies in the sub-tropical zone or the warm temperate zone. This location is responsible for large variations in land forms, climate, soil types and natural vegetation in the country. To the south east and south west of the mainland, lie the Andaman and Nicobar islands and the

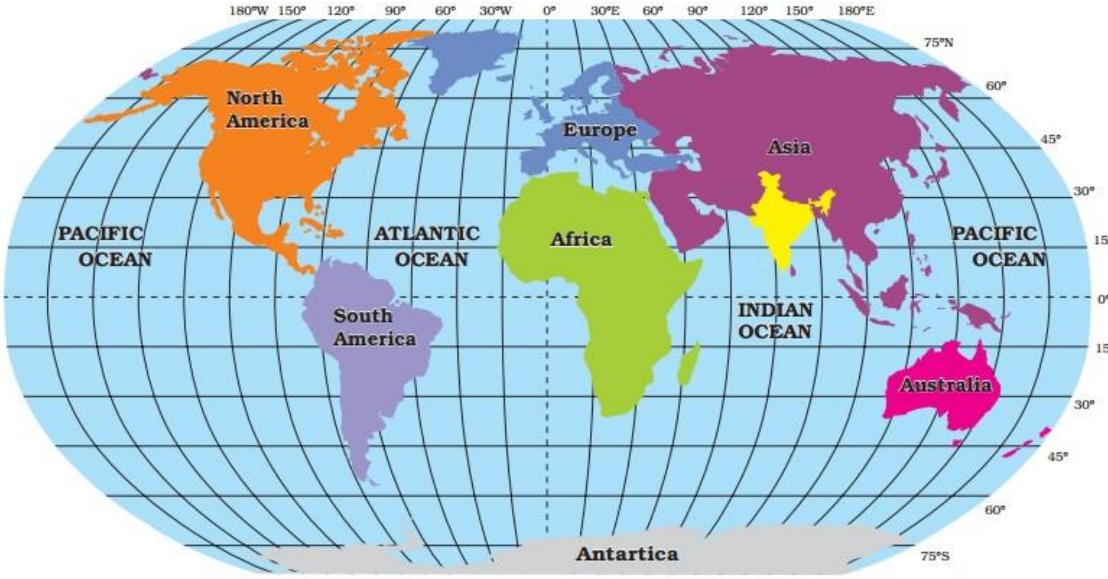


Figure 1 – India in the world

Lakshadweep islands in Bay of Bengal and Arabian Sea respectively. Andaman and Nicobar islands make southern boundary of India Union at 6°45'E in Bay of Bengal. The southernmost point of the India Union “Indira Point” got submerged under the sea water in 2004 during the Tsunami.

If you work out the latitudinal and longitudinal extent of India, they are roughly about 30 degrees, whereas the actual distance measured from north to south extremity is 3,214 km, and that from east to west is only 2,933 km (figure 2). Why is it so? This is because the east-west distance between two successive meridians of longitude along the equator is at its maximum - 111 km. This, however, goes on decreasing as one moves from the equator to the poles, where it is zero. This is because all the meridians of longitude merge in a single point at the poles - both North and South. On the other hand, the north-south distance between any two successive parallels of latitude along any meridian of longitude remains almost uniform, i.e., 111 km.

1.1. Indian Standard Time (IST)

While the sun rises in the northeastern states about two hours earlier as compared to Jaisalmer, the watches in Dibrugarh, Imphal in the east and Jaisalmer, Bhopal or Chennai in the other parts of India show the same time. Why does this happen? What is Indian Standard Time (IST)? What is the use of standard meridian (figure 2)? Variation of nearly 30degree in longitude causes a time difference of

Student Notes:

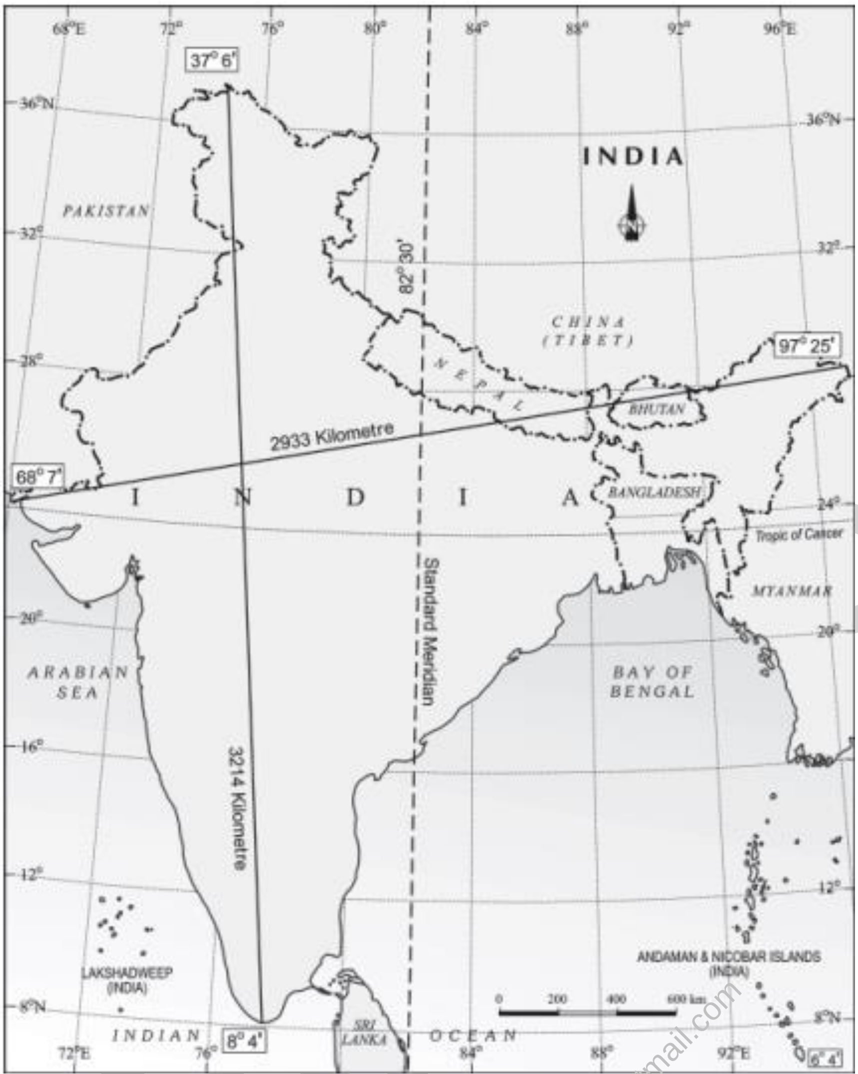


Figure 2 – India: Extent and Standard Meridian

nearly two hours between the easternmost and the westernmost parts of our country. Standard meridian is an imaginary line used for reckoning standard time. For the convenience of all, each country chooses its standard meridian in a multiple of 7°30'. India's standard meridian passes through 82° 30'E.Time along this Standard Meridian of India passing through Mirzapur (in Uttar Pradesh) is taken as the standard time for the whole country and known as IST with a time offset of UTC + 5:30.

There is a continuous demand from northeastern states to have separate time zone. Currently, the single time zone causes problems for them, especially in summers when daybreak comes as early as 4:30am around the summer solstice. A farmer in Assam can start work one hour before her or his counterpart in a state like Gujarat. Tea gardens in Assam have for years set their clocks an hour ahead of the rest of the country.

1.2. Size

The land mass of India has an area of 3.28 million square km. India's total area accounts for about 2.4 per cent of the total geographical area of the world; whereas it sustains17.5per cent of the world population. India is the seventh largest country of the world. India has a land boundary of about 15,200 km and the total length of the coast line of the mainland including Andaman and Nicobar and Lakshadweep is 7,516.6 km.

Figure 3 – India: Administrative Division

India is bounded by the young fold mountains in the northwest, north and north east. South of about 22° north latitude, Indian Landmass begins to taper, and extends towards the Indian Ocean, dividing it into two seas, the Arabian Sea on the west and the Bay of Bengal on its east. The Peninsular shape of India makes climate of southern India differ from that of Northern India. Vast sandy expanse of Marusthal in Rajasthan and marshy great Rann of Kachchh make western boundary of the India.

1.3. India's Administrative Division

India, that is Bharat, is a union of states. India has total twenty-eight[1] states and seven Union Territories (Figure 3). New Delhi is the capital of India. Rajasthan is the largest state while Goa is the smallest state in terms of geographical area. The Tropic of Cancer (23° 30'N) passes through Mizoram, Tripura, West Bengal, Jharkhand, Chhattisgarh, Madhya Pradesh, Rajasthan and Gujarat (8 states). Jammu and Kashmir makes northern border while Tamil Nadu makes southern border. Similarly, Gujarat and Arunachal Pradesh are the western most and eastern most states respectively. Except Madhya Pradesh, Chhattisgarh, Jharkhand, Haryana, all states share international or marine boundary.

1.4. India and the World

The Indian landmass has a central location between the East and the West Asia. India is a southward extension of the Asian Continent. The Trans Indian Ocean routes provide a strategic

[1] As of Jan 2013 Telangana is in process.

central location to India. It is India's eminent position in the Indian Ocean which justifies the naming of an Ocean after it.

India is part of Indian sub-continent and shares boundary with every country of this region. Land neighbours of India include Pakistan, Afghanistan, China, Nepal, Bhutan, Myanmar and Bangladesh. Most of our boundary with Pakistan and Bangladesh is almost **man-made** while boundary with other countries largely form a **natural boundary**. Sri Lanka and Maldives are the two island countries located in the Indian Ocean, which are our neighbours. Sri Lanka is separated from India by the Gulf of Mannar and Palk Strait.

2. Physical Formation of India

Earth of the distant past was a very different planet than the one we know today. Over these long years, it has undergone many changes brought about primarily by the endogenic and exogenic forces. We have already studied about the movement of Indian plate which started its northward journey about 200 million years ago. This northward movement of the Indian plate is still continuing and it has significant consequences on the physical environment of the Indian subcontinent. Here, we will study about geological structure of India. The geological regions of India are broadly divided into three parts - (i) The Peninsular Block; (ii) The Himalayas; and (iii) Indo-Ganga-Brahmaputra Plain.

2.1. The Peninsular Block

The plateau of Peninsular India exhibits a complex system of geological structures. It has some of the oldest rocks of the world from the Precambrian period and the youngest rocks of the Quaternary period. The features of this block have developed over period of time. Since the Cambrian period, the Peninsula has been standing like a rigid block with the exception of some of its western coast which is submerged beneath the sea and some other parts changed due to tectonic activity without affecting the original basement. It has been subject to various vertical movements and block faulting. The rift valleys of the Narmada, relict and residual mountains like the Aravali hills, and block fault like Malda fault in the Eastern India are example of it.

Figure 4 – Peninsular block

Student Notes:

This region contains all types of rocks - igneous, metamorphic and sedimentary rocks. For instance, limestone, sandstone sedimentary rocks are found in river valleys. Coal belts of Peninsular India were developed during the Gondwana period. The black soil of Deccan is due to outpouring of huge quantity of lava during Cretaceous period.

The northern boundary of the Peninsular Block may be taken as an irregular line running from Kutch along the western flank of the Aravali Range near Delhi and then roughly parallel to the Yamuna and the Ganga as far as the Rajmahal Hills and the Ganga delta (figure 4). Apart from these, Rajasthan in the west and the Karbi Anglong and the Meghalaya Plateau in the northeast are also extensions of this block. The northeastern parts are separated by the Malda fault in West Bengal from the Chotanagpur plateau. In Rajasthan, the desert and other *desert–like* features overlay this block.

2.2. The Himalayas

The Himalayas are geologically young, weak and flexible and structurally fold mountains unlike the rigid and stable Peninsular Block. The disintegration of Pangaea, about 200 million years ago, led to the formation of a long Tethys sea between the Lauretian Shield and Gondwanaland. This sea was occupying the region of Himalayas called geosyncline. About 65-30 million years ago, the Indian plate came very close to the Eurasian plate and started subducting under it (figure 5). This caused lateral compression due to which the sediments of the Tethys were squeezed and folded into three parallel ranges of the Himalayas. Since the northward movement of the Indian plate is still continuing, these mountains are still subjected to endogenic forces apart from exogenic forces. It is said that the height of the Himalayan peaks is still increasing.

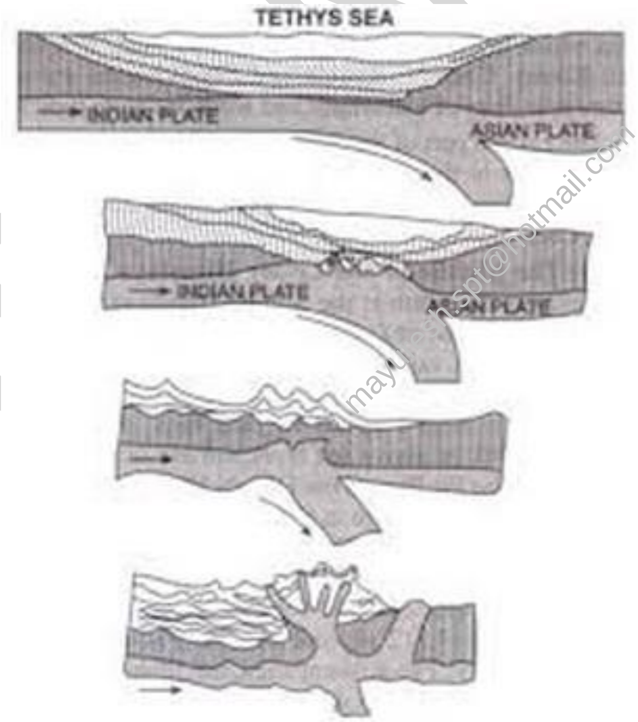


Figure 5 – Plate tectonics and evolution of Himalayas

The Himalayas consist of four litho tectonic mountain ranges, namely (i) the Trans-Himalaya; (ii) the Greater Himalaya; (iii) the Lesser Himalaya; and (iv) the Shiwalik. The first phase of uplift produced the ranges of Trans Himalayas around 65 million years ago. Subsequent uplift led to formation of Greater Himalayas, Lesser Himalayas and Shiwalik mountain ranges.

Student Notes:

2.2.1. Syntaxial Bends of the Himalayas

The structures and trends of the Himalaya change sharply at both ends of the range, defining bends called "syntaxes." It develops along the edges of two colliding plates near the zone of active collision. The western syntaxial bend is near Nanga Parbat where the Indus has cut deep gorge. The geological formations here take sharp hair-pin bends as if they were bent around pivotal points obstructing them. There is a similar hair-pin bend in Arunachal Pradesh where the mountains take a sharp bend from the eastern to southern direction after crossing the Brahmaputra river.

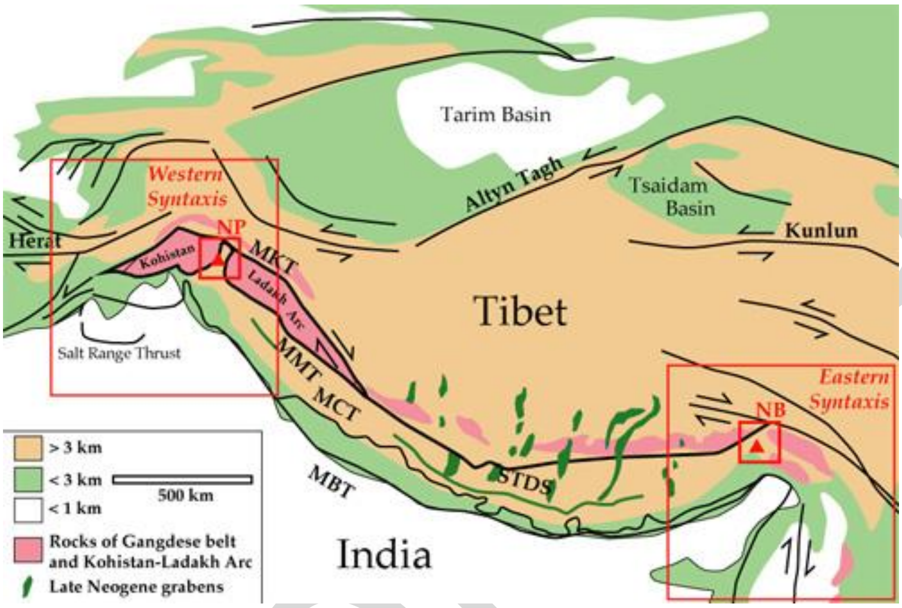


Figure 6 – Himalaya's syntaxes at NP (Nanga Parbat) and NB (Namcha Barwa)

2.3. Indo-Ganga-Brahmaputra Plain

The third geological division of India comprises the plains which lie to the south of Shiwalik formed by the river system Indus, the Ganga and the Brahmaputra. Originally, it was a geo-synclinal depression which attained its maximum development during the third phase of the Himalayan mountain formation approximately about 64 million years ago. It is an aggradational plain formed by the alluvial deposits of rivers originating in Himalayas in north and the Peninsular plateau in South. Since then, it has been gradually filled by the sediments brought by the Himalayan and Peninsular rivers. Average depth of alluvial deposits in these plains ranges from 1,000-2,000 m. Some geologists are of the opinion that Great plains are a remnant of the Tethys Sea. After the upheaval of Shiwalik, the remaining part of the Tethys was left as a large trough. Because the Himalayas were rising during that period, rivers experienced rejuvenation and greater quantity of eroded material which increased the thickness of alluvium in this trough (figure 7).

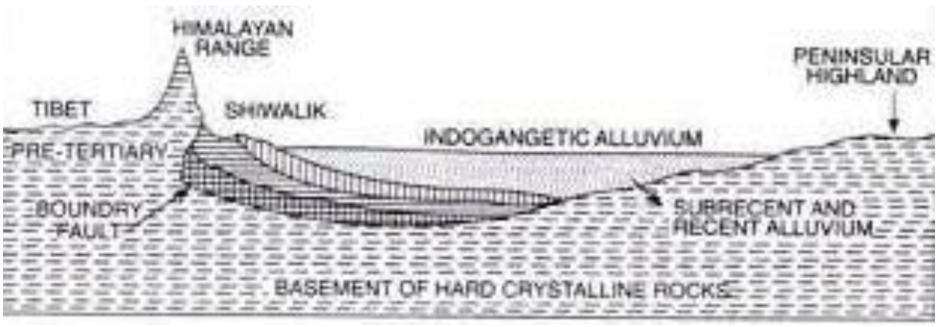


Figure 7 – The great plains of India

CENEZOIC ERA	HOLOCENE		
	PLEISTOCENE	From upper Pliocene to Plistocene.	Upliftment of Outer Himalays (Siwalik). Main Boundary Thrust (MBT) formed.
	PLIOCENE MIOCENE	From Miocene to Plioceen.	Main Central Thrust (MCT) formed. Upliftment of Lesser Himalaya (Second Phase).
	OLIGOCENE EOCENE	From Eocene to Oligocene.	Upliftment of Central Himalaya.
	PALAEOCENE	From late Cretaceous to Eocene.	Collision of Indian and Eurasion plate begins. (Continent collision)— Indus Tsangpo Suture Zone formed (ITSZ) formed.
MESOZOIC ERA	CRETACEOUS (LATE)		Extensive eruption of basalt leading to formation of Deccan Lava Plateau. Enclosure of Tethys which started shrinking.
PALAEOZOIC ERA	UPPER	From Caboniferous to Permian.	Deposition in three great graben like basin-Mahanadi, Damodar and Godavari known as Gondwana deposits. (Region with rich cola reserves).
	LOWER	From Cambrian to Carboniferous (Early).	Formation conspicusouly absent.
PRECAMBRIAN	UPPER PROTEROZOIC		Vindhyan syneclise - devoid of metalliferous minerals. Vindhyan Mountain — formed of shales, slates, clay and limestone.
	MIDDLE PROTEROZOIC		Satpura, Shillong Plateau. Formation and deposition in Cuddapah depression.
	EARLY PROTERZOIC		Delhi and Aravalli orogeny took place.
	CLOSE ARCHEAN		Dharwar system—cover whole length of Karnataka. (Region with iron ore reserves).
	LATE ARCHEAN		Peninsular Gneiss and Eastern Ghat formation.
	MIDDLE ARCHEAN		Singhbhum and Keonjhar Orogeny (rich iron ore reserves).

Table 1 – Geological Time Scale of India

3. Physiography

'Physiography' deals with the study of the surface features and landforms of the earth. It is the outcome of structure, process and the stage of development. There are significant variations among the different regions of India in terms of their geological structure. The relief and physiography of India has been greatly influenced by the geological and geomorphological processes active in the Indian subcontinent. The land of India is characterized by great diversity in its physical features. The north has a vast expanse of rugged topography consisting of a series of mountain ranges with varied peaks, beautiful valleys and deep gorges. The south consists of stable table land with highly dissected plateaus, denuded rocks and developed series of scarps. In between these two lies the vast north Indian plain. Based on these macro variations, India can be divided into the six physiographic divisions as shown in figure 8.

Student Notes:

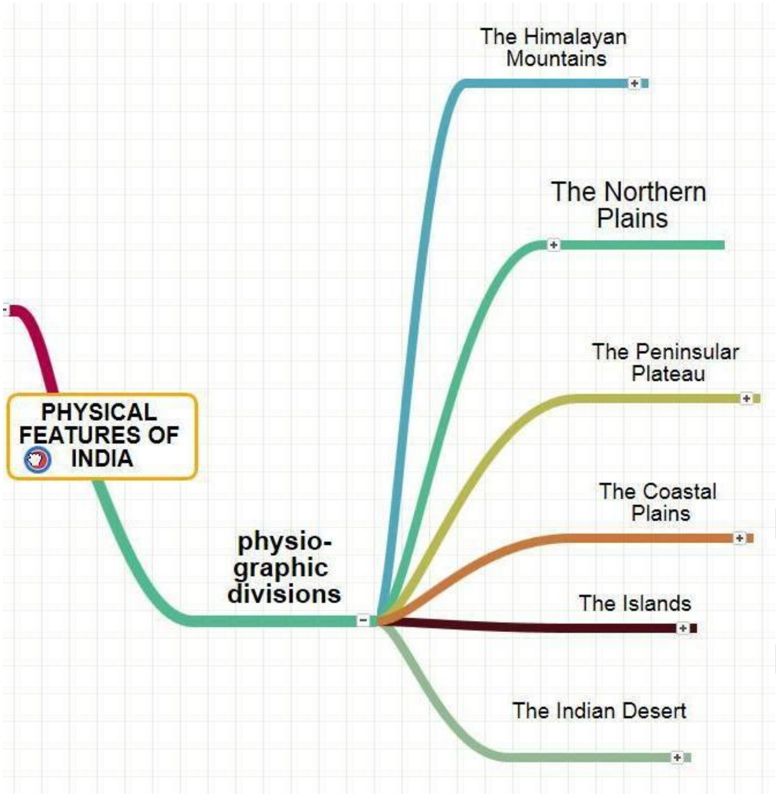


Figure 8 – Physiographic division of India

3.1. Himalayan Mountains

The North and Northeastern Mountains consist of the Himalayas and the Northeastern Hills. The Himalayas represent the loftiest and one of the most rugged mountain barriers of the world. The altitudinal variations are greater in the eastern half than those in the western half. They are steeper at their southern side as compared to northern side. They are separated from the plains by the Himalayan Front Fault (HFF).Himalayas are not only the physical barrier, they are also a climatic, drainage and cultural divide.

The general orientation of these ranges is from northwest to the southeast direction in the northwestern part of India. Himalayas in the Darjiling and Sikkim regions lie in an east west direction, while in Arunachal Pradesh they are from southwest to the northwest direction. In Nagaland, Manipur and Mizoram, they are in the north south direction. They form an arc, which covers a distance of about 2,400 Km. Its width varies from 400 Km in Kashmir to 150 Km in Arunachal Pradesh.

Longitudinal division of Himalayas include – Trans-Himalayas, the Greater Himalayas, the Lesser Himalayas and the Shiwaliks (Figure 9). The trans-Himalayas are about 40km wide and contain Tethys sediments which are underlain by 'Tertiary granite'. Trans-Himalayas in clue Karakoram, Ladakh and Zaskar Mountain ranges in India. The Greater Himalayas rise abruptly like a wall. They are 25 km wide with an average height above 6100m. Almost all the lofty peaks of the Himalayas Mt. Everest, Kanchenjunga, Nanga-Parbat lies in this zone. This mountain range has very few gaps mainly provided by the antecedent rivers, otherwise it is the most continuous range in the Himalayan system. The width of lesser Himalayas is about 80 km with an average height of 1300 – 4600 m. This region is subjected to extensive erosion due to heavy rainfall, deforestation and urbanization. The Shiwalik extend over a width of 10-50 Km and have an altitude varying between 900 and 1100 metres. These ranges are composed of unconsolidated sediments brought down by rivers from the main Himalayan ranges

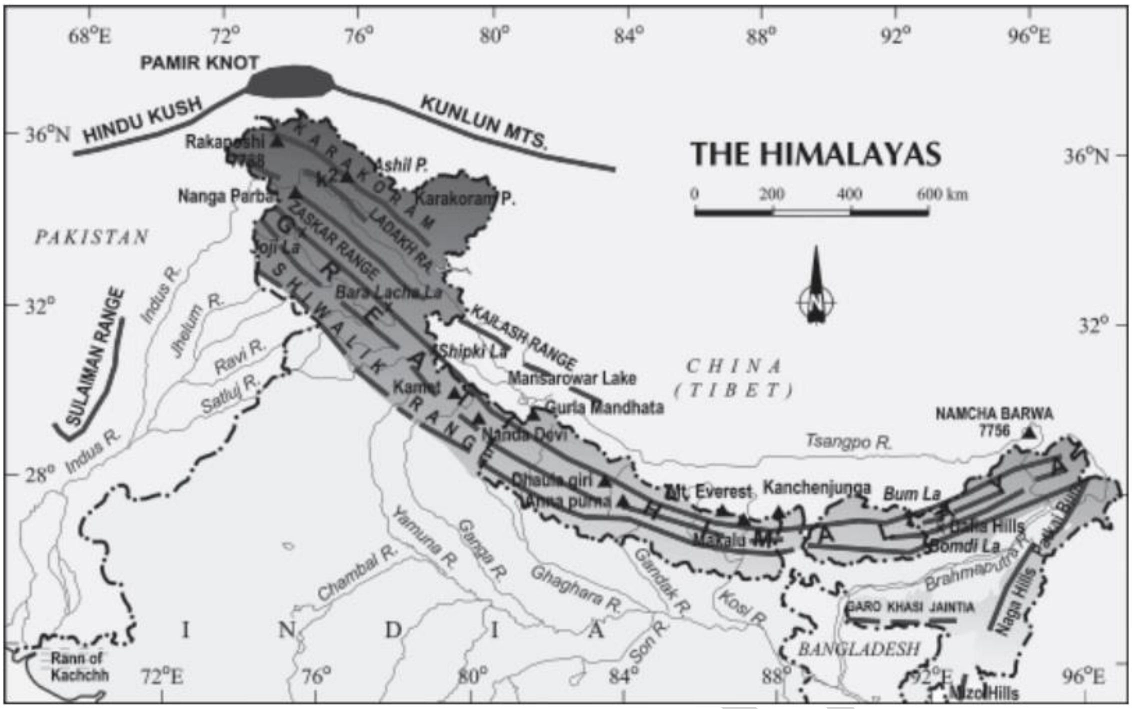


Figure 9 – Himalayas and Northeastern Hills

located farther north. Shiwalik are absent beyond Nepal. Landforms like gorges, V-shaped valleys, rapids, waterfalls etc. are indicative of youthful stage of Himalayas. Cross sectional view of Himalayan system is given below (figure 10).

Figure 10 - Cross sectional view of Himalayan system

Besides the longitudinal divisions, the Himalayas have been divided on the basis of regions from west to east. These divisions have been generally demarcated by river valleys. On the basis of relief, alignment of ranges and other geomorphologic features, the Himalayas can be divided into the five sub-divisions as shown in figure 11.

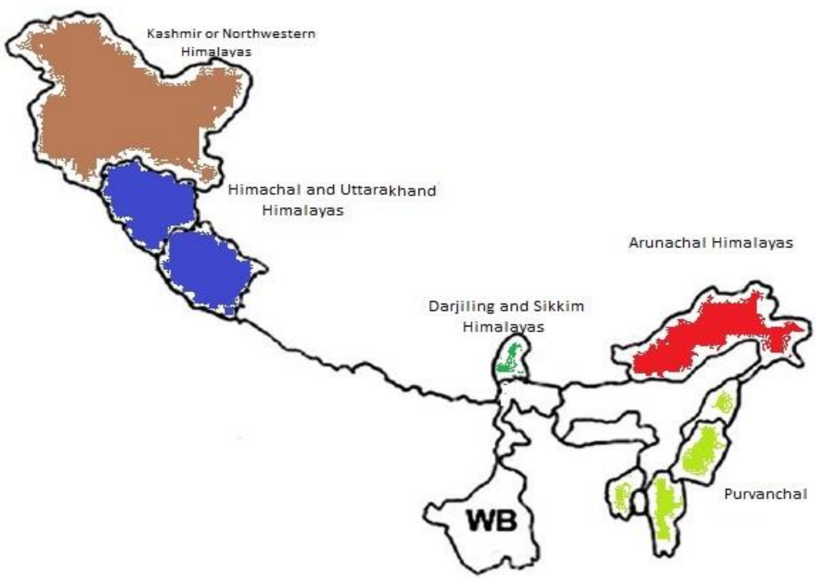


Figure 11 – Himalayan – Longitudinal Divisions

3.1.1. Kashmir or Northwestern Himalayas

Sprawling over an area of about 350,000 sq km, the range stretches about 700km in length and 500 km in width. This division is lying between Indus and Ravi rivers. With an average height of 3000m, it has the largest number of glaciers in India such as Baltoro, Siachen glaciers. Kashmir Himalayas comprise a series of ranges such as the Karakoram, Ladakh, Zaskar and Pir Panjal. The northeastern part of the Kashmir Himalayas, Ladakh, is a cold desert, which lies between the Greater Himalayas and the Karakoram ranges. It is one of the loftiest inhabited regions of the world. Between the Great Himalayas and the Pir Panjal range, lies the world famous valley of Kashmir and the famous Dal Lake.

A special feature of Kashmir valley is **Karewas** formation which is thick deposits of glacial clay and other materials embedded with moraines and useful for saffron cultivation. The southernmost part of this region consists of longitudinal valleys known as **'duns'** such as Jammu duns and Pathankot duns etc. Some of the important passes of the region are Zoji La on the Great Himalayas, Banihal on the Pir Panjal, Photu La on the Zaskar and Khardung La on the Ladakh range. Important fresh lakes such as Dal and Wular and salt water lakes such as Pangong Tso and Tso Moriri are also in this region. Some famous places of pilgrimage such as Vaishno Devi, Amarnath Cave, Charar -e-Sharif, etc. are also located here. Srinagar, capital city of the state of Jammu and Kashmir is located on the banks of Jhelum river.

3.1.2. Himachal and Uttrakhand Himalayas

Stretching over Himachal Pradesh, it occupies an area of about 83,000 sqkm. All the three ranges – the Greater, the Lesser (which is locally known as Dhaoladhar in Himachal Pradesh and Nagtibha in Uttaranchal) and the Shiwalik Himalayas – are well represented in this region. This division lies between Ravi and Kali rivers. It is drained by two major river systems of India, i.e. the Indus and the Ganga. Tributaries of the Indus include the river Ravi, the Beas and the Satluj, and the tributaries of Ganga flowing through this region include the Yamuna and the Ghaghara. The northernmost part of the Himachal Himalayas is an extension of the Ladakh cold desert. Gangotri, Milam and Pindar are the main glaciers of Uttarakhand.

The northern slopes of this region are clothed with thick forests and show plains and lakes, while the southern slopes are rugged and forest clad. The famous Valley of flowers is also situated in this region of Himalayas. The two distinguishing features of this region from the point of view of physiography are the 'Shiwalik' and 'Dun formations' such as Chandigarh-Kalka

Student Notes:

dun, Nalagarh dun. Dehra Duns the largest of all the duns with an approximate length of 35-45 km and a width of 22-25 km.

In the Great Himalayan range, the valleys are mostly inhabited by the Bhotias. These are nomadic groups who migrate to 'Bugyals' (the summer grasslands in the higher reaches) during summer months and return to the valleys during winters. The places of pilgrimage such as the Gangotri, Yamunotri, Kedarnath, Badrinath and Hemkund Sahib are also situated in this part. The region is also known to have **five famous Prayags - Vishnu Prayag, Nand Prayag, Karn prayag, Rudra Prayag and Dev Prayag,** in the descending flow sequence of their occurrence. In this section of Lesser Himalayas, the altitude between 1,000-2,000 m especially attracted to the British colonial administration, and subsequently, some of the important hill stations such as Dharamshala, Mussoorie, Shimla, and the cantonment towns and health resorts such as Shimla, Kasauli etc. were developed in this region.

3.1.3. Darjiling and Sikkim Himalayas

The Darjiling and Sikkim Himalayas are flanked by Nepal Himalayas in the west and Bhutan Himalayas in the east. It is relatively small but is a most significant part of the Himalayas. As compared to the other sections of the Himalayas, these along with the Arunachal Himalayas are conspicuous by the absence of the Shiwalik formations. In place of the Shiwaliks here, the 'duar formations' are important, which have also been used for the development of tea gardens. Known for its fast-flowing rivers such as Tista, it is a region of high mountain peaks and deep valleys. Kanchenjunga (8598 m), 3rd highest peak of the world, is situated on the border of India and Nepal. This region has very few passes. The passes of Nathu-La and Jelep-La connect Gangtok (Sikkim) with Lhasa, Tibet (China).

The higher reaches of this region are inhabited by Lepcha tribes while the southern part, particularly the Darjiling Himalayas, has a mixed population of Nepalis, Bengalis and tribals from Central India. The British, taking advantage of the physical conditions such as moderate slope, thick soil cover with high organic content, well distributed rainfall throughout the year and mild winters, introduced tea plantations in this region. Sikkim and Darjiling Himalayas are also known for their scenic beauty and rich flora and fauna, particularly various types of orchids.

3.1.4. Arunachal Himalayas

Arunachal Himalayas extend from the east of the Bhutan Himalayas up to the Diphu pass in the east. The general direction of the mountain range is from southwest to northeast. In this part, the Himalayas rise very rapidly from the plains of Assam. Some of the important mountain peaks of the region are Kangtu and Namcha Barwa. These ranges are dissected by fast-flowing rivers from the north to the south, forming deep gorges. Brahmaputra flows through a deep gorge after crossing Namcha Barwa. Some of the important rivers are the Kameng, the Subansiri, the Dihang, the Dibang and the Lohit. These are perennial with the high rate of fall, thus, having the highest hydro-electric power potential in the country. Due to heavy rainfall, fluvial erosion is quite pronounced here. Few important passes of this region are Bomdi La, Diphu , Pangsau La etc.

An important aspect of the Arunachal Himalayas is the numerous ethnic tribal communities inhabiting in these areas. Some of the prominent ones from west to east are the Monpa, Daffla, Abor, Mishmi, Nishi and the Nagas. Most of these communities practise Jhumming (shifting cultivation). This region is rich in biodiversity which has been preserved by the indigenous communities. Due to rugged topography, the inter-valley transportation linkages are nominal. Hence, most of the interactions are carried through the duar region along the Arunachal-Assam border.

3.1.5. Eastern Hills and Mountains or Purvanchal

Eastern hills or Purvanchal are part of the Himalayan mountain system. On the southern border of Arunachal Pradesh, the Himalayas take a southerly turn and the ranges are arranged in a north-south direction. They are known by different local names. In the north, they are known as Patkai Bum (Arunachal Pradesh), Naga hills (Nagaland), the Manipur hills (Manipur) and in the south as Mizo or Lushai hills (Mizoram).

Most of these ranges are separated from each other by numerous small rivers. The Barak is an important river in Manipur and Mizoram. The physiography of Manipur is unique by the presence of a large lake known as 'Loktak' lake at the centre, surrounded by mountains from all sides. Mizoram which is also known as the 'Molassis basin' is made up of soft unconsolidated deposits. Most of the rivers in Nagaland form the tributary of the Brahmaputra. These are low hills, inhabited by numerous tribal groups practicing Jhum cultivation.

3.2. The Northern Plains

The northern plains of India are remarkably homogeneous surface with an imperceptible slope. In fact, they are a featureless alluvial fertile plains formed by the alluvial deposits brought by the rivers – the Indus, the Ganga and the Brahmaputra along with their tributaries and Vindhyan rivers flowing towards north. The plain extends from the arid and semi-arid areas of Rajasthan in the west to Brahmaputra valley in the east. The average width of these plains varies between 150-300 km. The maximum depth of alluvium deposits varies between 1,000-2,000 m. Its average height is 200 metres above the mean se level. Due to a very gentle slope towards the sea, the rivers in this plain flow very leisurely and at times even sluggishly. The slope from Varanasi upto the mouth of Ganga is only 10 cm. per km. The land around Ambala is a bit more elevated.

Due to almost flat land, changing river courses in the areas of frequent floods is a unique geomorphic process in the plains. The Kosi (The Sorrow of Bihar) is one of two major tributaries of Ganga, the other river being Gandak, draining the plains of north Bihar, the most flood-prone area of India. Over the last 250 years, the Kosi River has shifted its course over 120 kilometres and the unstable nature of the river is attributed to the heavy silt which it carries during the monsoon season (figure 12).From north to south, northern plains can be divided into three major zones: the Bhabar, the Tarai and the alluvial plains. The alluvial plains can be further divided into the khaddar and the Bhangar.

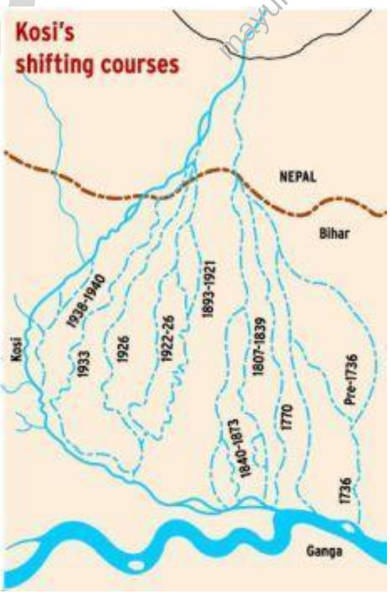


Figure 12 – Shifting course of river Kosi in last 250 years

3.2.1. The Bhabar Plain

Bhabar is a narrow belt ranging between 8-10 km parallel to the Shiwalik foothills at the break-up of the slope. Its width is, however, more in the western plains than in the eastern plains of Assam. The streams and rivers coming from the mountains deposit heavy materials of rocks and boulders, and at times, disappear in this zone due to high porosity. These rivers carry very coarse load with them. This load becomes too heavy for the streams to be carried over gentler gradients and gets dumped and spread as a broad low to high cone shaped deposit called alluvial fan ath the foothills of Shiwalik. Usually, the streams which flow over fans are not confined to their original channels for long and shift their position across the fan forming many channels called distributaries. The Bhabar tract is not suitable for cultivation of crops. Only big trees with large roots thrive in this region. The inhabitants are largely the cattle keeping Gujjars.

3.2.2. The Tarai Tract

South of the Bhabar is the Tarai belt, with an approximate width of 10-20 km where most of the streams and rivers re-emerge without having any properly demarcated channel, thereby, creating marshy and swampy conditions known as the Tarai. Unlike Bhabar tracts, Tarai is wider in the eastern parts of the Great plains, especially in Brahmaputra valley due to heavy rainfall.

This has a luxurious growth of natural vegetation and houses a varied wild life. Many parts of the Tarai, especially in Uttarakhand, Uttar Pradesh, Haryana, Punjab and Jammu, have been reclaimed, for agricultural crops such as sugarcane, rice, wheat, maize etc. This marshy tract is infested with mosquitoes and infamous for Japanese Encephalitis (JE) disease.

3.2.3. Bhangar Plains

The south of Tarai is a belt consisting of old and new alluvial deposits known as the Bhangar and Khadar respectively. The Bhangar represents the upland alluvial tracts formed by the older alluviums. The largest part of the northern plains is formed of this older alluvium. The Bhangar formations were deposited during the middle Pleistocene period. The Bhangar land lies above the flood limits of the rivers. The soil is dark in colour, rich in humus content and productive. It contains concentration and nodules of impure calcium carbonate or kankar.

3.2.4. Khadar Plains

New alluvial deposits along the courses of the rivers are known as the khadar lands. Himalayan rivers have more flood area in the eastern India and thus, Khadar plains are wider here as compared to western area. The khadar tracts are enriched by fresh deposits of silt every year during the rainy season. The khadar land consists of sand silt, clay and mud. Most of the Khadar land has been brough under the cultivation and devoted to sugarcane, rice, wheat, maize, oilseeds.

Together alluvial plains (Khadar and Bhangar) are stretched over 100kms from north to south direction. These plains have characteristic features of mature stage of fluvial erosional and depositional landforms such as sand bars, meanders, oxbow lakes and braided channels. The Brahmaputra plains are known for their riverine islands and sand bars. It is also home to first green revolution that took place in 1960s-70s in India.

3.2.5. The Delta Plains

The mouths of these mighty rivers also form some of the largest deltas of the world, for example, the famous Sunderbans delta. Otherwise, this is a featureless plain with a general elevation of 50-150 m above the mean sea level. The deltaic plains are extension of the Khadar land. It covers 1.9 lakh sqkm of area in lower reaches of the Ganga River. In fact, it is an area of deposition as the river flows in this tract sluggishly. The deltaic plain consists of old mud, new mud and marsh.

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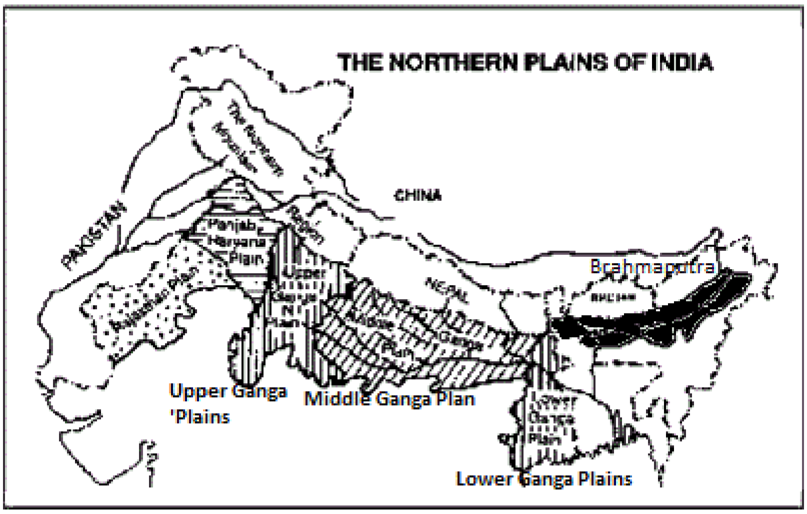

Figure 13 – Different section of northern plains of India

On the basis of geo-climatic and topographical characteristics, the northern plains of India may be divided into the following four meso-regions, namely (i) the plains of Rajasthan; (ii) the Punjab-Haryana plains; (iii) the Ganga plains; and (iv) the Brahmaputra Plains (figure 13).

3.2.6. The Plains of Rajasthan

They lie to the west of Aravallis. These plains cover a total area of about 175,000 sqkm. A substantial part of this plain has been formed by the recession of the sea as is evidenced by the presence of salt water lakes such as Sambhar lake near Jaipur city. During the Permo-carboniferous period, the greater part of the Rajasthan plain was under the sea. It has several dry beds of rivers like Saraswati which indicate that the area earlier was fertile. At present, the greater part of these plains is a desert covered with sand dunes and barchans. The Indira Gandhi canal has led to intensive agriculture in north-western Rajasthan.

3.2.7. The Punjab Haryana Plains

Stretching over an area of about 650km from northeast to southwest and 300km from west to east, the Punjab-Haryana plain is an aggradational plain, deposited by Satluj, Ravi and Beas rivers. Delhi ridge divides plains from the Gangetic plain. The height of the plains varies from 300 m in the north to 200 m in south east. The general direction of slope is from northeast to southwest and south. A plain between two rivers is called doab such as Bist doab between the Beas and Satluj.

3.2.8. The Ganga Plains

The Ganga plains lie between the Yamuna catchment in the west to the Bangladesh border in the east. It is about 1400km in length and has an average width of 300km. the general gradient of the plain is about 15cm per km. The ganga plains can be subdivided into the following sub-regions

- <u>The upper Ganga plain</u> – includes the Ganga-Yamuna Doab, Rohilakhand division and parts of the Agra division. The catchment area of the Yamuna river makes its western boundary, Shiwalik in the north. Its height varies from 100m to 300m. Kali, Sharda are other rivers feeding these plains. It is one of the most productive plains of India in which the Green revolution is a big success. Main crops grown here are sugarcane, wheat, rice, maize, mustard, vegetables etc.
- <u>The middle Ganga plain</u> – sprawling over an area of 150, 000 sqkm, it includes central and eastern Uttar Pradesh, Bihar up to Muzaffarpur and patna. It has thick alluvial deposits with

less kankar. Being a low gradient plain, the rivers often change their courses in this region as described above about Kosi river. Son, Gandak are major tributaries of Ganga.

- The lower ganga plain – extends from Patna to the Bay of Bengal. It is bordered by Assam, Bangladesh in the east and Chotanagpur plateau in the west and Sundarban delta in the south. It is drained also by Tista, Sankosh, Mahananda, Damodar, Subarnarekha rivers. These plains have filled faults with sediment created during movement of Indian plate. Ganga is divided into several distributaries in the delta region. Hooghly is the best example of a distributary of Ganga.

3.2.9. The Brahmaputra Plain

Stretching over an area of around 56,000sqkm, it is the eastern most part of plains. It is about 720 km long, 80 km wide and altitude varies from 30 m to 130 m. The region is surrounded by high mountains except in western side. Assam valley is characterized by a steep slope along northern margin. **Majuli with area of around 930sqkm is the largest river island of India and the second largest of world.** But this island is undergoing severe erosion and needs special protection. The tributaries descending from Himalayas form a series of alluvial fans. The fertile valley is conducive to grow rice and jute. It is also famous for its tea and two national parks – Kaziranga and Manas.

3.3. The Peninsular Plateau

The Great Peninsular plateau is a tableland composed of the old crystalline, igneous and metamorphic rocks. It lies to the South of the Great Northern Plains. It covers an area of about 16 lakh square km, i.e., about half of the total area of the country. It is an irregular triangle rising from the height of 150 m above the river plains up to an elevation of 600-900 m. Delhi ridge in the northwest, (extension of Aravalis), the Rajmahal hills in the east, Gir range in the west and the Cardamom hills in the south constitute the outer extent of the peninsular plateau. However, an extension of this is also seen in the northeast, in the form of Shillong and Karbi-Anglong plateau separated from Peninsular by Malda fault. One of the distinct features of the peninsular plateau is the black soil area known as Decean Trap. This is of volcanic origin hence the rocks are igneous. When Indian plate was moving over Reunion hotspot, basalt lava spread to form these igneous rocks. Actually these rocks have denuded over time and are responsible for the formation of black soil.

The Peninsular India is made up of a series of patland plateaus such as the Hazaribagh plateau, the Palamu plateau, the Ranchi plateau, the Malwa plateau, the Coimbatore plateau and the Karnataka plateau, etc. This is one of the oldest and the most stable landmass of India. The general elevation of the plateau is from the west to the east, which is also proved by the pattern of the flow of rivers. Rivers such as Krishna, Kaveri, Godavari, all rise from Western Ghats, makes delta in the Bay of Bengal side. Plateau has been subjected to large scale denudation. Its mountains are generally of relic type. Because of their old age, all the rivers have almost attained their base level and have built up broad and shallow valleys. Some of the important physiographic features of this region are tors, block mountains, rift valleys, spurs, bare rocky structures, series of hummocky hills and wall-like quartzite dykes offering natural sites for water storage.

This Peninsular plateau has undergone recurrent phases of upliftment and submergence accompanied by crustal faulting and fractures. These spatial variations have brought in elements of diversity in the relief of the peninsular plateau. The northwestern part of the plateau has a complex relief of ravines and gorges. The ravines of Chambal, Bhind and Morena are some of the well-known examples. On the basis of the prominent relief features, the peninsular plateau can be divided into three broad groups: (i) The Deccan Plateau; (ii) The Central Highlands; and (iii) The Northeastern Plateau.

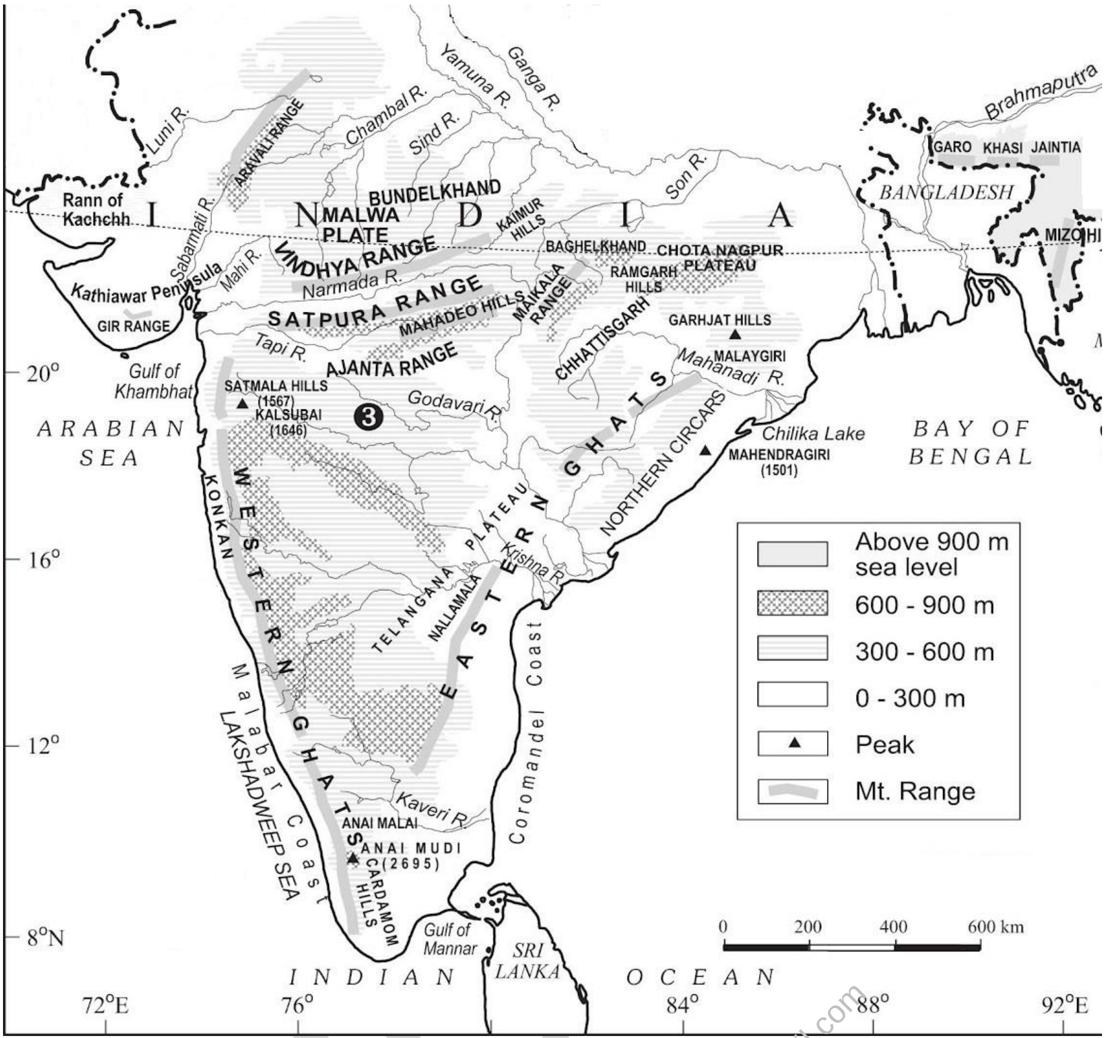

Figure 14 – Peninsular India: Relief

3.3.1. The Deccan Plateau

This physiographic division is the largest region (about 7 lakh square km) of the Great Indian Plateau. The shape of this plateau is triangular and lies to the south of the river Narmada. This is bordered by the Western Ghats in the west, Eastern Ghats in the east and the Satpura, Maikal range and Mahadeo hills in the north.The Satpura range is formed by a series of scarped plateaus on the south, generally at an elevation varying between 600-900 m. It is a classic example of the relict mountains which are highly denuded and form discontinuous ranges. The Deccan Plateau is higher in the west and slopes gently eastwards.

Western Ghats are locally known by different names such as Sahyadri in Maharashtra, Nilgiri hills in Karnataka and Tamil Nadu and Anaimalai hills and Cardamom hills in Kerala. These are block mountains formed due to the downwarping of a part into the Arabian Sea. Western ghats lie parallel to the western coast from mouth of Tapi rover to Kanyakumari. The western slope is steeper as compared to gentle eastern slope. Thal, Bhor and pal Ghats are major passes of Western Ghats. The Eastern Ghats stretch from the Mahanadi Valley to the Nigiris in the south. The Eastern Ghats are discontinuous and irregular and dissected by rivers such as Mahanadi, the Godavari, the Krishna, the Kaveri draining into the Bay of Bengal. Shevroy Hills and the Javadi Hills are located to the southeast of the Eastern Ghats.

Western Ghats are comparatively higher (900-1600m) in elevation and more continuous than the Eastern Ghats (600m). Their average elevation is about 1,500 m with the height increasing

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from north to south. 'Anaimudi' (2,695 m), the highest peak of Peninsular plateau is located on the Anaimalai hills of the Western Ghats followed by Dodabetta (2,637 m) on the Nilgiri hills. Mahendragiri (1,501 metres) is the highest peak in the Eastern Ghats. The Eastern and the Western Ghats meet each other at the Nilgiri hills.

3.3.2. The Central Highlands

It extends between Vindhayalchal range in South and Great Northern Plains in nroth. The Aravallis form the west-northwestern edge of the Central Highlands. An eastern extension of the Central Highland is formed by the Rajmahal hills. Malwa plateau forms the dominant part of the Central Highlands. The part of the Central Highlands which extends to the east of Malwa Plateau is known as Bundelkhand and is further followed by Baghelkhand and the well known Chhotanagpur Plateau with large mineral reserves. Chhotanagpur is drained by Damodar river. The Mahadeo Hills, Kaimur Hills and Maikal Range lie towards further east. The valley of Narmada has been formed due to the subsidence of the land mass between the Vindhyas and the Satpuras.

The general elevation of the Central Highlands ranges between 700-1,000 m and it slopes towards the north and northeastern directions. Most of the tributaries (Chambal, Sind, Betwa, Ken) of the river Yamuna have their origin in the Vindhyan and Kaimur ranges. Banas, tributary of the river Chambal, originates from the Aravalli in the west.

The extension of the Peninsular plateau can be seen as far as Jaisalmer in the West, where it has been covered by the longitudinal sand ridges and crescent-shaped sand dunes called barchans. Aravallis hills extend from Gujarat, through Rajasthan to Delhi in the northeasterly direction for a distance of about 700 km till Delhi. The highest peak of the Aravalli hills is Gurushikhar (1722 m) near Mt. Abu, hill station.

3.3.3. The North-Eastern Plateau

It is an extension of the main Peninsular plateau in the northeast– locally known as the Meghalaya and Karbi-Anglong Plateau. It is separated by Malda fault from the Chotanagpur Plateau. Later, this depression got filled up by the deposition activity of the numerous rivers. The Meghalaya plateau is further sub-divided into three: (i) The Garo Hills; (ii) The Khasi Hills; (iii) The Jaintia Hills, named after the tribal groups inhabiting this region. An extension of this is also seen in the Karbi Anglong hills of Assam. Shillong is the highest peak in this plateau.

Similar to the Chotanagpur plateau, the Meghalaya plateau is also rich in mineral resources like coal, iron ore, sillimanite, limestone and uranium. This area receives maximum rainfall from the south west monsoon. As a result, the Meghalaya plateau has a highly eroded surface

3.4. The Indian Desert

The Indian desert lies towards the western margins of the Aravali Hills. It is a land of undulating topography dotted with longitudinal dunes and barchans. This region receives low rainfall below 150 mm per year; hence, it has arid climate with low vegetation cover. Low precipitation and high evaporation makes it a water deficit region. Streams appear during the rainy season. Luni is the only large river in this region. It is believed that during the Mesozoic era, this region was under the sea. This can be corroborated by the evidence available at wood fossils park at Aakal and marine deposits around Brahmsar, near Jaisalmer. Land features present here are mushroom rocks, shifting dunes and oasis. the desert can be divided into two parts: the northern part is sloping towards Sindh and the southern towards the Rann of Kachchh.

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3.5. The Coastal Plains

The Peninsular plateau is flanked by stretch of narrow coastal strips, running along the Arabian Season the west and the Bay of Bengal on the east.

3.5.1. Western Coastal Plains

West Coastal Plain extends along the Arabian Sea from the Rann of Kutchch in the north to Kanyakumari in the south. These plains are an example of submerged coastal plain. Because of this submergence it is a narrow belt and provides natural conditions for the development of ports and harbours. Kandla, Mazagaon, JLN port Navha Sheva, Marmagao, Mangalore, Cochin, etc. are important natural ports.

Extending from the Gujarat coast in the north to the Kerala coast in the south, the western coast may be divided into following divisions – the Kutch and Kathiawar coast in Gujarat, Konkan coast in Maharashtra, Goan coast and Malabar coast in Karnataka and Kerala respectively. The plains of Gujarat are made up of black soil. There are a number of long and narrow lagoons on Malabar Coast. Kochi port is situated on one of the lagoons. These plains are narrow in the middle and get broader towards north and south. The rivers flowing through this coastal plain do not form any delta. The Malabar coast has got certain distinguishing features in the form of 'Kayals'(backwaters), used for fishing, inland navigation, tourism.

3.5.2. Eastern Coastal Plains

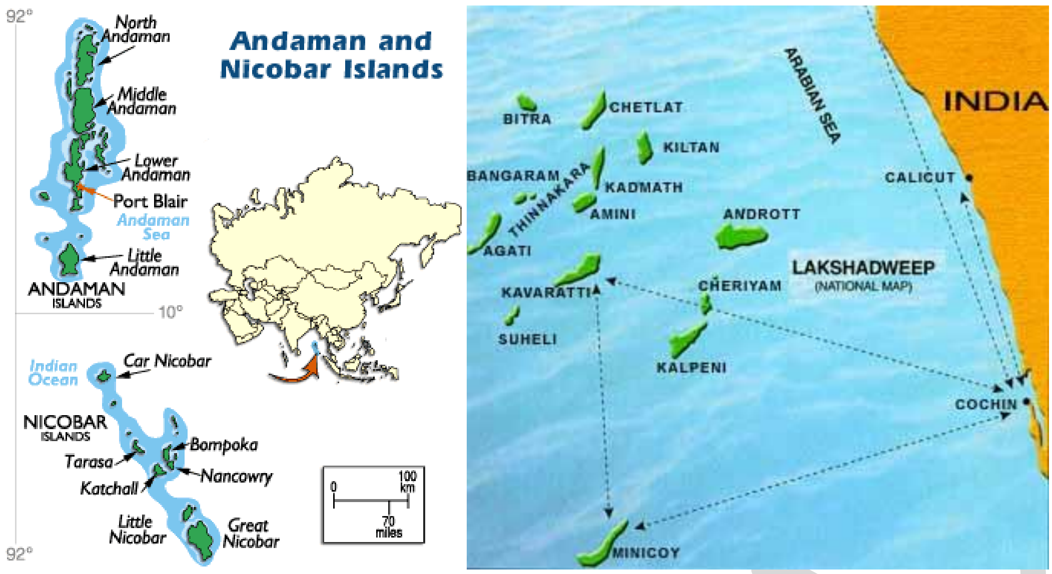
The eastern coastal plain is broader, leveled and is an example of an emergent coast. These plains are formed by the alluvial fillings. The monotony of plains is broken by the numerous hills. In the northern part, it is referred to as the Northern Circar, while the southern part is known as the Coromandal Coast. There are well developed deltas here, formed by rivers Mahanadi, Krishna, Godavari, Kaveri etc.Lakes such as Chilika, Pulicat, and Kolluru are the famous lagoons of this plain. Because of its emergent nature, it has less number of ports and harbours. The continental shelf extends up to 500 km into the sea, which makes it difficult for the development of good ports and harbours. Paradip, Visakhapatnam, Ennor, Chennai, Tuticorin are important ports along eastern coast. Rice is the intensively grown here.

3.6. The Islands

There are two major island groups in India – one in the Bay of Bengal and the other in the Arabian Sea.

3.6.1. Andaman and Nicobar Islands

The Bay of Bengal island groups consist of about 572 islands/islets. These are situated roughly between 6°N-14°N and 92°E -94°E (Figure 15a). The entire group of island is divided into two broad categories – the Andaman in the north and the Nicobar in the south. They are separated by a water body which is called the Ten degree channel. It is believed that island group is an extension of submarine mountains. However, some smaller islands are volcanic in origin. Barren island, the only active volcano in India is also situated here. The coastal line has some coral deposits, and beautiful beaches. These islands lie close to equator and thus, experience equatorial climate. The islands have thick forest cover due to heavy convectional rainfall.



(a) – Andaman and Nicobar Islands **(b) Lakshadweep Islands**

Figure 15 – Island groups of India

3.6.2. Lakshadweep Islands

Lakshadweep Islands are situated in the Arabian Sea, at a distance of 280-480km off the coast of Kerala. These are scattered between 8°N-12°N and 71°E -74°E (Figure 15b). All these islands are of coral origin. They have been built up by corals. Only 11 out of 36 islands are inhabited. The largest island among these, the Minicoy, has an area of 4.5 square km only. The entire group of islands is broadly divided by the Eleventh degree channel, north of which is the Amini Island and to the south of the Canannore Island. Landform features are storm beaches consisting of unconsolidated pebbles, shingles, cobbles and boulders.

In overall, it would be clear that each region complements the other and makes the country richer in its natural resources. The northern mountains are the major sources of water and forest wealth. The northern plains are the granaries of the country. They provide the base for early civilisations. The plateau is a storehouse of minerals, which has played a crucial role in the industrialisation of the country. The coastal region and island groups provide sites for fishing and port activities.

4. Drainage

Rivers have always been of supreme importance to man, providing focal points for habitation, water for cultivation and avenues to travel, water power and recreation. A river or stream is a body of water flowing in a channel. The term '**drainage'** describes the river system of an area. It is an integrated system of a river and its tributaries which collect and funnel surface water to the sea. The area drained by a single river system is called a **drainage basin**. The boundary line separating one drainage basin from the other is known as the **watershed**. A river drains the water collected from a specific area, which is called its '**catchment area'**. The catchments of large rivers are called **river basins** while those of small rivulets and rills are often referred to as watersheds. Watersheds are small in area while the basins cover larger areas.

4.1. Drainage Pattern

A geometric arrangement of streams in a region; determined by slope, differing rock resistance to weathering and erosion, climate, hydrologic variability, and structural controls of the landscape is known as drainage pattern. The rivers that existed before the upheaval of the

Himalayas and cut their courses by making gorges in the mountains are knows as the **antecedent rivers**. Indus, Satluj, Ganga are some important antecedent rivers. The rivers which follow general direction of slope are known as the **consequent rivers**. Godavari and Krishna etc. rivers descending from the Western Ghats are some consequent rivers.

The drainage pattern resembling the branches of a tree is known as "**dendritic**" the examples of which are the rivers of northern plain. It develops where the river channel follows the slope of the terrain. When the rivers originate from a hill and flow in all directions, the drainage pattern is known as '**radial**'. The rivers originating from the Amarkantak range present a good example of it. When the primary tributaries of rivers flow parallel to each other and secondary tributaries join them at right angles, the pattern is known as '**trellis**'. It develops where hard and soft rocks exist parallel to each other. Right bank tributaries of Brahmaputra rivers make trellis pattern while the left bank tributaries exhibit the

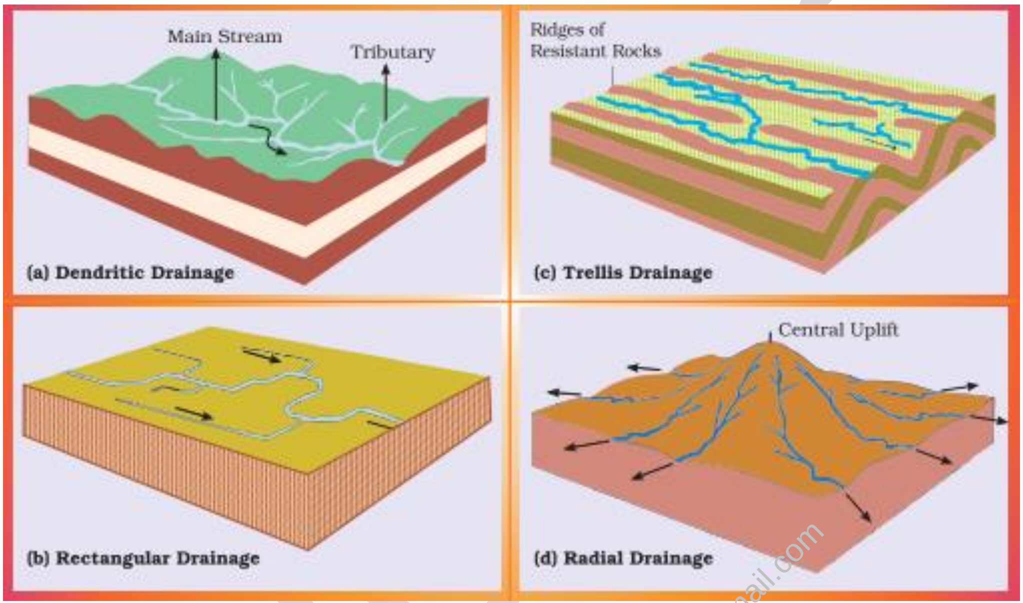


Figure 16–Drainage patterns

dendritic pattern. When the rivers discharge their waters from all directions in a lake or depression, the pattern is known as '**centripetal**'. It is reverse of radial and occurs in the areas of karst topography. A combination of several patterns may be found in the same drainage basin.

4.2. Drainage System of India

The drainage systems of India are mainly controlled by the broad relief features of the subcontinent. Indian drainage system may be divided on various bases. On the basis of discharge of water (orientations to the sea), it may be grouped into: (i) the Arabian Sea drainage; and (ii) the Bay of Bengal drainage. They are separated from each other through the Delhi ridge, the Aravalis and the Sahyadris (water divide is shown by a line in Figure 17).Many rivers have their sources in the Himalayas and discharge their waters in the Bay of Bengal except Indus river system which discharge into Arabian Sea. Ganga, Yamuna, Gandak, Tista and Brahmaputra rivers are major example of it.

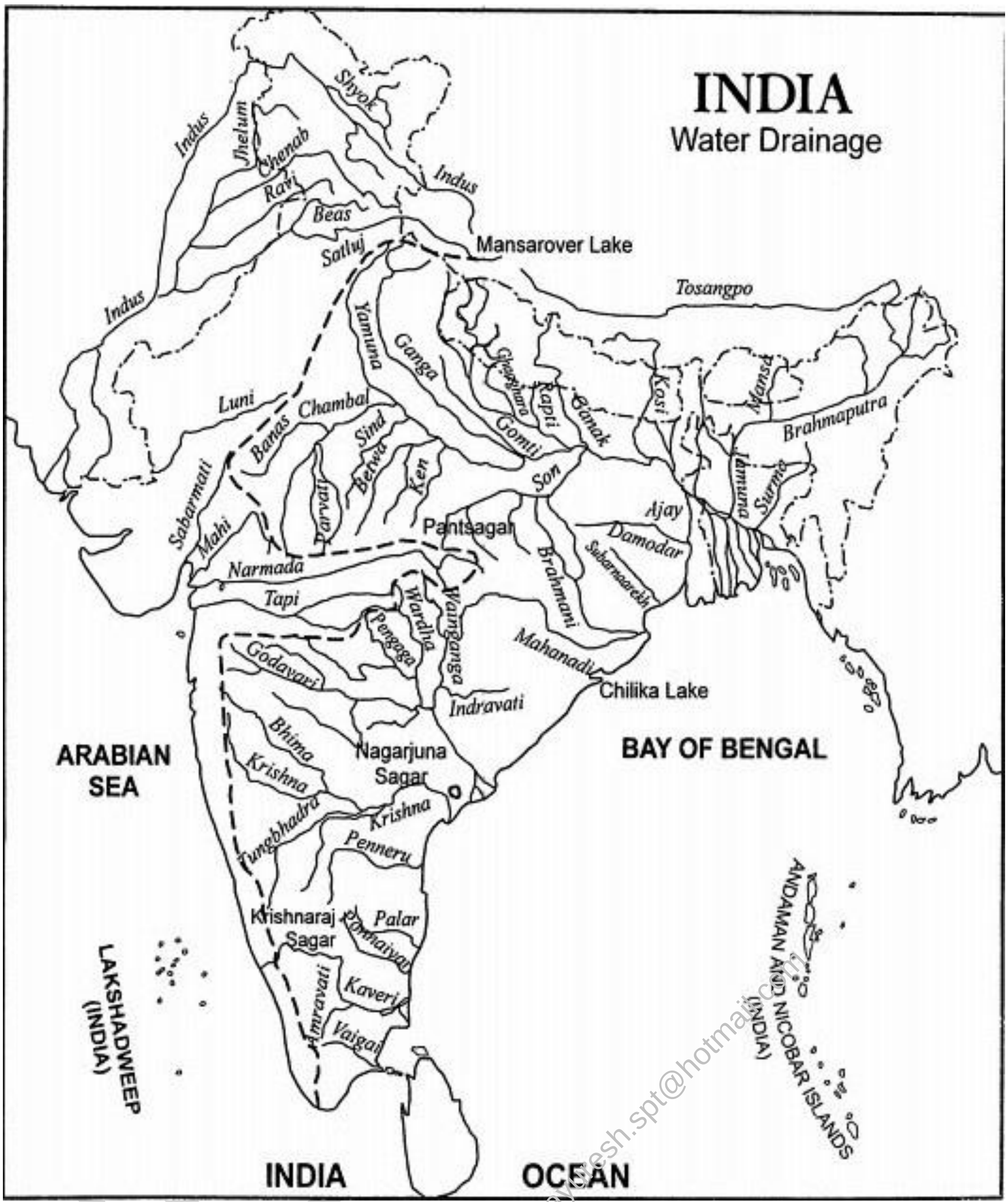


Figure 17 – Water divide between east flowing and west flowing rivers

Large rivers flowing on the Peninsular plateau have their origin in the Western Ghats and discharge their waters in the Bay of Bengal. Krishna, Godavari, Kaveri, Tungabhadra are some example of it. The Narmada and Tapi are two large rivers which are exceptions. They along with many small rivers discharge their waters in the Arabian Sea. These small rivers have origin in Western Ghats such as Mandavi, Netravati, Sharavati, and Periyar rivers.

Nearly 77 per cent of the drainage area consisting of the Ganga, the Brahmaputra, the Mahanadi, the Krishna, etc. is oriented towards the Bay of Bengal while 23 per cent comprising the Indus, the Narmada, the Tapi, the Mahi and the Periyar systems discharge their waters in the Arabian Sea.

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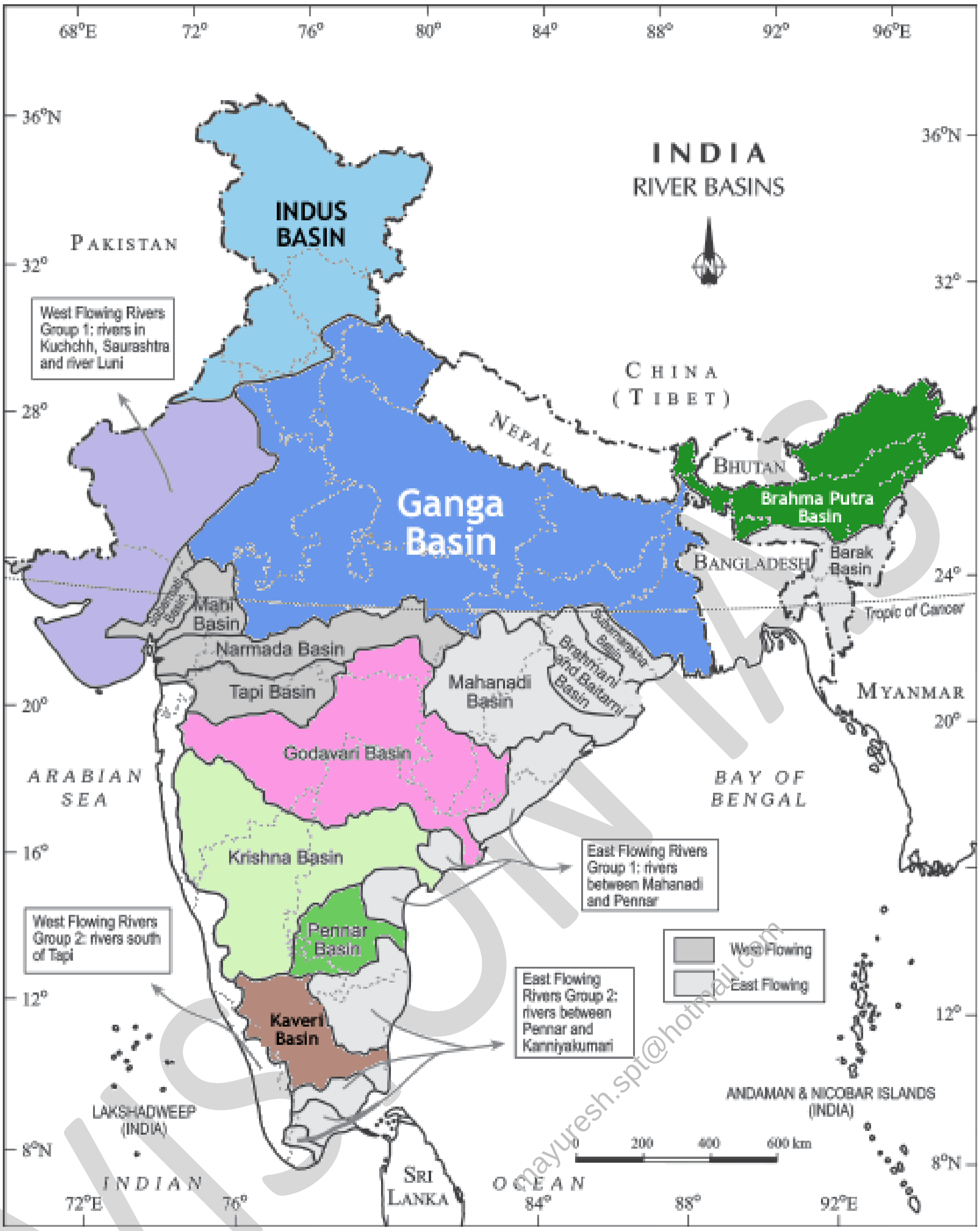

Figure 18 – Major river Basins of India

On the basis of mode of origin, the drainage of India may be divided into (i) Himalayan Drainage; and (ii) Peninsular drainage. However, many of the Peninsular rivers like the Chambal, Betwa, Ken, Son are tributaries of Ganga river system which originate in Himalayas (figure 17).

On the basis of the size of the watershed, the drainage basins of India are grouped into three categories: (i) Major river basins with more than 20,000 sq. km of catchment area (figure 18). It includes 14 drainage basins such as the Ganga, the Indus, the Godavari, the Krishna, the Brahmaputra, the Mahanadi, the Narmada, the kaveri, the Tapi, the Pennar, the Brahmani, the Mahi, the Sabarmati, the Barak, the Suvarnarekha; (ii) Medium river basins with catchment area between 2,000-20,000 sq. km incorporating 44 river basins such as the Kalindi, the Periyar, the Meghna, etc.; and (iii) Minor river basins with catchment area of less than 2,000 sq. km include fairly good number of rivers flowing in the area of low rainfall.

4.3. The Himalayan Drainage System

The Himalayan drainage system has evolved through a long geological history. There is no unanimity among geologists about the origin of the Himalayan rivers. However, it is believed that a mighty river, namely Shiwalik or Indo-Brahma was flowing west from Assam to Sind and finally discharged into Gulf of Sind during Miocene period. The remarkable continuity of the Shiwalik and its lacustrine origin and alluvial deposits consisting of sands, silt, clay, boulders and conglomerates support this viewpoint.

This mighty Shiwalik river was dismembered into three main systems which are now called as Indus, Ganga and Brahmaputra systems (figure 19).The dismemberment is attributed to upheaval in the Western Himalayas including uplift of the Potwar Plateau (or Delhi Ridge). This ridge act as a water divide between Indus and Ganga river systems. Similarly, the down thrusting of the Malda fault (area between Rajmahal Hills and the Meghalaya Plateau) caused the Ganga and the Brahamputra systems to flow towards Bay of Bengal. The giant gorges, sudden bends towards South and other such features are evidence in support that these rivers are older than the Himalayas.

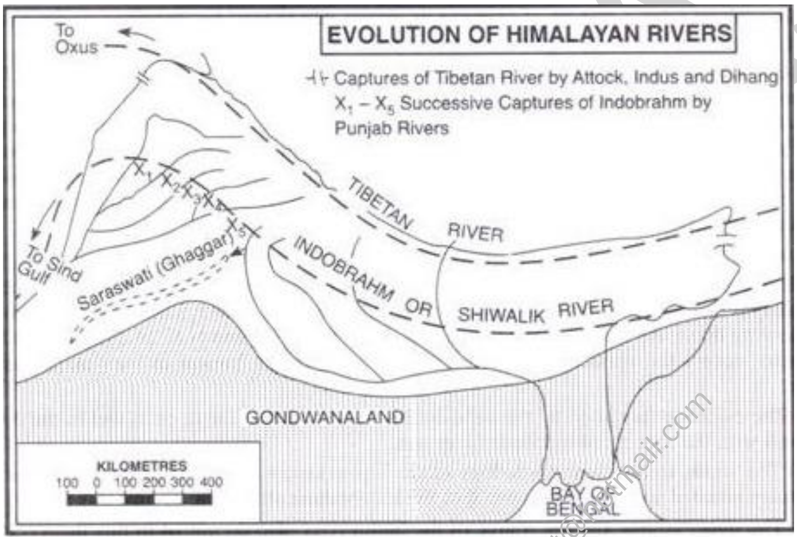

Figure 19 – evolution of Himalayan Drainage

Currently, Indus, Ganga and Brahamputra with their respective tributaries make major drainage systems of Himalayas. Since these are fed both by melting of snow and precipitation, rivers of this system are perennial.

4.3.1. Landforms of Himalayan Rivers

The Himalayan rivers are in their youthful stage carving out a number of erosional landforms. These rivers pass through the giant gorges carved out by the erosional activity carried on simultaneously with the uplift of the Himalayas. Satluj, Indus forms great gorges near Gilgit and Sukkur respectively. Besides deep gorges, these rivers also form V-shaped valleys, rapids and waterfalls in their mountainous course. While entering the plains, they form depositional features like flat valleys, ox-bow lakes, flood plains, braided channels, and deltas near the river mouth. In the Himalayan reaches, the course of these rivers is highly tortuous, but over the plains they display a strong meandering tendency and shift their courses frequently.

4.3.2. The Indus System

The Indus (Sindhu) is one of the most important drainage systems of the Indian subcontinent and one of the largest in the world. It covers an area of 11, 65,000 sq. km and length of 2,880 km, out of which 321, 289 sqkm area and 1,114 km length is in India. The Indus is the westernmost of the Himalayan rivers in India. Indus has origin from a glacier near Bokar Chu in the Kailash Mountain range in the Tibet province of China. In Tibet, it is known as 'Singi Khamban; or Lion's mouth. After flowing in a constricted valley in Tibet, it follows a long, nearly straight course between the Ladakh and Zaskar ranges in the northwest direction where it receives Zaskar below Leh town. It cuts across the Ladakh range, forming a spectacular gorge near Gilgit which is 5200m in height. In this region, transverse glaciers and landslides periodically dam the river. River passes Nanga Parbat and turns south-west to enter Pakistan near Chillar in the Dardistan region. In the Jammu and Kashmir, Indus receives a number of Himalayan tributaries such as the Shyok, the Gilgit, the Hunza, the Nubra, the Shigar, the Gasting and the Dras. Right bank tributaries such as the Khurram, the Tochi, etc. originate in Sulaiman ranges. Down in the Punjab province of Pakistan, Indus receives **'Panjnad'**, five rivers of Punjab, namely the Satluj, the Beas, the Ravi, the Chenab and the Jhelum. River finally drains into the Arabian Sea, east of Karachi city. These rivers do not meet Indus separately but as a single river.

The Jhelum (Vitasta) rises from a spring at Verinag Spring situated at the foot of the Pir Panjal. It flows through Srinagar and the Wular lake before entering Pakistan through a deep narrow gorge. It joins the Chenab in Pakistan. It is the most important river of Kashmir.

The Chenab (Asikni) flows in India for about 1180km draining around 26,755 sqkm area. It is the largest tributary of the Indus. It is formed by two streams, the Chandra and the Bhaga, which join at Tandi near Keylong in Himachal Pradesh. Hence, it is also known as Chandrabhaga. Major hydro power plants installed in Chenab are Salal, Baghliar, and Dulhasti.

The Ravi (Parushni) river flows for about 725 km and drains 6000 sqkm area in India. It rises near the Rohtang Pass in Kullu hills in Himachal Pradesh, very close to the source of the Beas river. It flows through the famous Chamba valley. It drains an area lying between Pir Panjal and Dhauladhar ranges. It also cuts a gorge in Dhaula Dhar range. In plains of Punjab, it runs along the Indo-Pak border and joins Chenab near Sarai Sidhu in Pakistan.

The Beas (Vipasa) river originates from the Beas Kund near the Rohtang Pass at an elevation of 4,000 m. The river flows through the Kullu valley and forms gorges at Kati and Largi in the Dhaula Dhar range. Further down, it flows through the Kangra valley. It enters the Punjab plains where it meets the Satluj near Harike in India's Punjab. Indira Gandhi Canal that feeds western Rajasthan has origin at Harike, confluence of Beas and Satluj.

The Satluj (Satadru) river rises from the Rakas Lake near Mansarovar (4,555m) in Tibet. This is an antecedent river. It flows almost parallel to the Indus for about 400 km before entering India, and comes out of a gorge across the Great Himalayas. It passes through the Shipki La (4300 m) on the Himalayan ranges at India-China border. It cuts the Zaskar ranges, Dhaula Dhar range, Shiwalik and finally enters the Punjab plains. It feeds the canal system of the Bhakra Nangal project.

The Ghaggar (Saraswati) is an inland drainage which rises in the talus fan of the Shiwalik near Ambala, Haryana. After entering the plains, it disappears but reappears at Karnal. Further on, the stream disappears near Hanumargarh in Bikaner. It is believed that it is an old tributary of the Indus.

4.3.3. The Ganga System

The Ganga is the most important river of India both from the point of view of its basin and cultural significance. The river has a length of 2,525 km. It is the largest river basin in India with about one-fourth area of the country under it. It rises in the Gangotri glacier near Gaumukh (3,900 m) in the Uttarakhand where it is known as the Bhagirathi. At **Devprayag**, the Bhagirathi meets the Alaknanda and both makes Ganga. The Alaknanda consists of the Dhauli and the

Vishnu Ganga which meet at **Vishnuprayag**. Pindar joins Alaknanda at **Karnaprayag** while Mandakini meets it at **Rudraprayag**. At Haridwar, Ganga enters into plains. Further on, it moves in west-east direction and split into two distributaries, namely the Bhagirathi and the Hugli in Bengal. Along with Brahmaputra, it makes largest delta of the world. The Ganga river is having a number of perennial and non-perennial rivers originating in the Himalayas in the north and the Peninsula in the south, respectively. It flows through major cities of India – Kanpur, Allahabad, Patna, and Kolkata.

The Yamuna river, the western most and the longest tributary of the Ganga, has its source in the Yamunotri glacier on the western slopes of Banderpunch range (6,316 km). It flows parallel to Ganga and finally meets the same at Allahabad (Prayag). The right bank tributaries involves the Chambal, the Sind, the Betwa and the Ken which originates in the Peninsular plateau while the Hindan, the Rind, the Sengar, the Varuna, etc. join it on its left bank. It is a major source to feed the canals of Haryana and Uttar Pradesh. It flows through cities such as Karnal, Delhi, and Agra.

The Gandak river comprises two streams, namely Kaligandak and Trishulganga. It rises in the Nepal Himalayas between Dhaluagiri and Mt. Everest. It enters the Ganga Plains of India in Champaran, Bihar and joins Ganga at Sonpur near Patna. This river changes its course frequently.

The Ghaghara originates in the glaciers of Mapchachungo. It comes out of the mountain, cutting a deep gorge at Shishapani. The river Sarda joins it in the plain before it finally meets the Ganga at Chhapra. It flows through famous Ayodhya town.

The Ramganga is the first major tributary to join the Ganga from its left near Kannauj. It rises in the Garhwal hills near Gairsain. A large dam has been built on this river near Kalagarh.

The Damodar drains the eastern parts of the Chotanagpur Plateau where it flows through a rift valley and finally joins the Hugli at Falta. The Barakar is its main tributary. Once known as the 'sorrow of Bengal', the Damodar has been now tamed by the Damodar Valley Corporation, a multipurpose project.

The Chambal rises near Mhow in the Malwa plateau from Vindhyan range and flows northwards through a gorge up wards of Kota in Rajasthan. From Kota, it traverses down to Bundi, Sawai Madhopur and Dholpur, and finally joins the Yamuna at Etawah. The Chambal is famous for its badland topography called the Chambal ravines. Ravines are being reclaimed for agricultural and pastoral activities. Banas river is its main tributary. The main dams across the river are Gandhi Sagar (Kota), Rana Pratap Sagar and Jawahar Sagar.

The Son originates from the Amarkantak plateau. It has length of 780km and drains areas of around 54,000 sqkm. After forming a series of waterfall at the edge of plateau, it reaches Arrah, west of Patna to join the Ganga.

The Sarda or Saryu river rises in the Milan glacier in the Nepal Himalayas where it is known as the Goriganga. Along the Indo-Nepal border, it is called Kali or Chauk, where it joins the Ghaghara. The Mahananda is another important tributary of the Ganga rising in the Darjiling hills. It joins the Ganga as its last left bank tributary in West Bengal.

4.3.4. The Brahmaputra System

The Brahmaputra is one of the largest river of not only India but the world. Its total length is 2900km and basin area is 5,80,000 sqkm (916 km and 1,87,00 sqkm in India). Its origin is in the Chemayungdung glacier of the Kailash range near the Mansarovar lake. From here, it flows parallel to the Greater Himalayas in the dry and flat Tibetan region where it is known as Tsangpo. It emerges as a turbulent and dynamic river after carving out a deep gorge in the Central Himalayas near Namcha Barwa (7,755 m). The river emerges from the foothills under the name of Siang or Dihang. It enters India west of Sadiya town in Arunachal Pradesh. It receives its main left bank tributaries, viz., Dibang or Sikang and Lohit; thereafter, it is known as the Brahmaputra.

In the Assam valley, its major left bank tributaries are the Burhi Dihing, Dhansari (South) and Kalang whereas the important right bank tributaries are the Subansiri, Kameng, Manas and Sankosh. The Brahmaputra enters into Bangladesh near Dhubri and flows southward. In Bangladesh, the Tista joins it on its right bank from where the river is known as the Yamuna. The Brahmaputra is well-known for floods, channel shifting and bank erosion. This is due to the fact that most of its tributaries are large, and bring large quantity of sediments owing to heavy rainfall in the region

4.4. The Peninsular Drainage System

The Peninsular drainage system is older than the Himalayan one. This is evident from the broad, largely-graded shallow valleys, and the maturity of the rivers. Rivers follow the relief pattern of the plateau. Except for the rivers flowing through fault valleys, the slope of all rivers is very gentle.

4.4.1. Evolution of Peninsular Drainage System

Three major geological events in the distant past have shaped the present drainage systems of Peninsular India: (i) Subsidence of the western flank of the Peninsula leading to its submergence below the sea during the early tertiary period. Generally, it has disturbed the symmetrical plan of the river on either side of the original watershed. Earlier the area to the west of the Western ghats was also a landmass in ancient times. At that time, rivers flowed in both directions from the water divide formed by the Ghats and there was a symmetrical distribution of rivers. (ii) Upheaval of the Himalayas when the northern flank of the Peninsular block was subjected to subsidence and the consequent trough faulting. The Narmada and The Tapi flow in trough faults and fill the original cracks with their detritus materials. Hence, there is a lack of alluvial and deltaic deposits in these rivers. (iii) Slight tilting of the Peninsular block from northwest to the southeastern direction gave orientation to the entire drainage system towards the Bay of Bengal during the same period.

4.4.2. River Systems

The Western Ghats situated near the western coast form the major water divide between the major Peninsular rivers, discharging their water in the Bay of Bengal and as small rivulets joining the Arabian Sea. Except Narmada and Tapi, all major rivers flow in east direction. The other major river systems of the Peninsular drainage are – the Mahanadi the Godavari, the Krishna and the Kaveri. Peninsular rivers are characterised by fixed course, absence of meanders and ephemeral flow of water. The Narmada and the Tapi which flow through the rift valley are, however, exceptions. Peninsular rivers receive water from Southwest monsoon and Tamil Nadu rivers gets water from retreating or northeast monsoon also.

4.4.3. East Flowing Rivers

The Mahanadi rises near Sihawa, Amarkantak hills in the highlands of Chhattisgarh and runs through Orissa to discharge its water into the Bay of Bengal. It is 851 km long and its catchment area spreads over 1.42 lakh sq. km. Some navigation is carried on in the lower course of this river. Deltaic stretch of this river is part of National Waterways 5(NW5).

The Godavari is the largest Peninsular river. It rises from the slopes of the Western Ghats in the Nasik district of Maharashtra. It is also called Dakshinganga. It is 1,465 km long with a catchment area spreading over 3.13 lakh sq. km 49 per cent of this, lies in Maharashtra. The Penganga, the Indravati, the Pranhita, and the Manjra are its principal tributaries. It forms a

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picturesque gorge in Eastern Ghats. The Godavari is subjected to heavy floods in its lower reaches. It is navigable only in the deltaic stretch. The river after Rajamundri splits into several branches forming a large delta.

The Krishna is the second largest east-flowing Peninsular river which rises from a spring near Mahabaleshwar. Its total length is 1,401 km. The Koyna, the Tungbhadra and the Bhima are its major tributaries. Its drainage basin is shared by Maharashtra, Karnataka and Andhra Pradesh.

The Kaveri rises in Brahmagiri hills (1,341m) of Kogadu district in Karnataka. Its length is 800 km and it drains an area of 81,155 sq. km. Since the upper catchment area receives rainfall during the southwest monsoon season (summer) and the lower part during the northeast monsoon season (winter), the river carries water throughout the year. It flows into the Bay of Bengal at Kaveripatnam. It drains parts of Tamil Nadu, Karnataka and Kerala. Its important tributaries are the Kabini, the Bhavani and the Amravati.

The Brahmani and the Subernarekha rivers drain a part of area between the Ganga and the Mahanadi into the Bay of Bengal. Their drainage area extends over parts of Bihar, Odisha, West Bengal and Madhya Pradesh. It supplies water to the Tata steel plant at Jamshedpur.

4.4.4. West Flowing Rivers

The Narmada originates on the western flank of the Amarkantak plateau at a height of about 1,057 m. Flowing in a rift valley between the Satpura in the south and the Vindhyan range in the north, it forms a picturesque gorge in marble rocks and Dhuandhar waterfall near Jabalpur. It meets the Arabian Sea south of Bharuch, forming a broad 27 km long estuary. Its length is 1312 km and catchment area of 98,796 sqkm. All the tributaries are very short and make trellis pattern. The Sardar Sarovar Project has been constructed on this river. Narmada has been joined with other Gujarat rivers to shift its water.

The Tapi is the other important westward flowing river. It originates from Multai in the Betul district of Madhya Pradesh and discharge in Surat district, Gujarat. It is 724 km long and drains an area of 65,145 sq. km. The Purna, Girna and Panjhra are its important tributaries.

Luni is the largest river system of Rajasthan, west of Aravali. It originates near Pushkar in two branches, i.e. the Saraswati and the Sabarmati, which join with each other at Govindgarh. It flows towards the west till Telwara and then takes a southwest direction to join the Rann of Kutch.

The Mahi river rises in the Satmala hills of the Vindhyan mountains. After flowing for 533km, it drains into the Gulf of Khambhat. The Sabarmati riverrises in the Aravalli hills and flows into Arabian Sea after flowing over a distance of 300km.

Small west flowing rivers are numerous which rises in the Western Ghats and have short runoff. The Shetruniji is one such river which rises near Dalkahwa in Amreli district. The Bhadra originates near Aniali village in Rajkot district. The Dhadhar rises near Ghantar village in Panchmahal district. The Vaitarna rises from the Trimbak hills in Nasik district at an elevation of 670 m. The Kalinadi rises from Belgaum district and falls in the Karwar Bay. The Sharavati is another important river in Karnataka flowing towards the west. The Sharavati originates in Shimoga district of Karnataka. Goa has two important rivers which can be mentioned here. One is Mandovi and the other is Juari. The longest river of Kerala, Bharathapuzha rises near Annamalai hills. It is also known as Ponnani. It drains an area of 5,397 sq. km. The Periyar is the second largest river of Kerala. Its catchment area is 5,243 sq. km.

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4.5. Comparison Between Himalayan and Peninsular Rivers

Difference between the rivers rising in the Himalayas and those rising in the Peninsular plateau are primarily a result of the differences between the two areas in terms of relief and climate. Following table shows major differences between these two groups.

S.N.	Aspects	Himalayan River	Peninsular River
1	Place of Origin	Himalayan mountain covered with glaciers	Peninsular plateau and central highland
2	Nature of flow	Perennial	Ephemeral
3	Type of drainage	Antecedent and Consequent leading to dendritic pattern	Super imposed, rejuvenated resulting in trellis, radial and rectangular Patterns
4	Nature of river	Long course, flowing through the rugged mountains experiencing headward erosion and river capturing; In plains meandering and shifting of Course;	Smaller, fixed course with well-adjusted valleys;
5	Catchment area	Very large basins	Relatively smaller basin
6	Age of the river	Young, active and deepening of valley	Old rivers with graded profile and lateral erosion
7	Irrigation	Flows through plains and canal system	Flows over uneven plateau; canals only in deltaic region
8	Hydro-electricity	Eastern region has very high potential and large dams are building up	Natural waterfalls for generating electricity

4.6. National River Linking Project

The idea of linking water surplus Himalayan rivers with water scarce parts of western and peninsular India has been doing the rounds for the past 150 years. The rivers of India carry huge volumes of water per year but it is unevenly distributed both in time and space. There are perennial rivers carrying water throughout the year while the non-perennial rivers have very little water during the dry season. During the rainy season, much of the water is wasted in floods and flows down to the sea. Similarly, when there is a flood in one part of the country, the other area suffers from drought. Such linkage is said to provide major benefits such as irrigation, assured drinking water, flood and draught prevention, generation of electricity, and inland navigation. Nevertheless, project is facing several challenges in its implementation. Project involves hundreds of billions of dollars that India could not afford. Water shortage Peninsular plateau has higher altitude compare to water surplus Ganges plains. Carrying water to higher level required either electricity to pump water or create chain of deep channels which seems very difficult in rocky Peninsular. Project will have to acquire lakhs of hectares of land. It will affect the ecosystem(submergence of forest land, deforestation, flora and fauna) and rehabilitation issue of lakhs of displaced persons.

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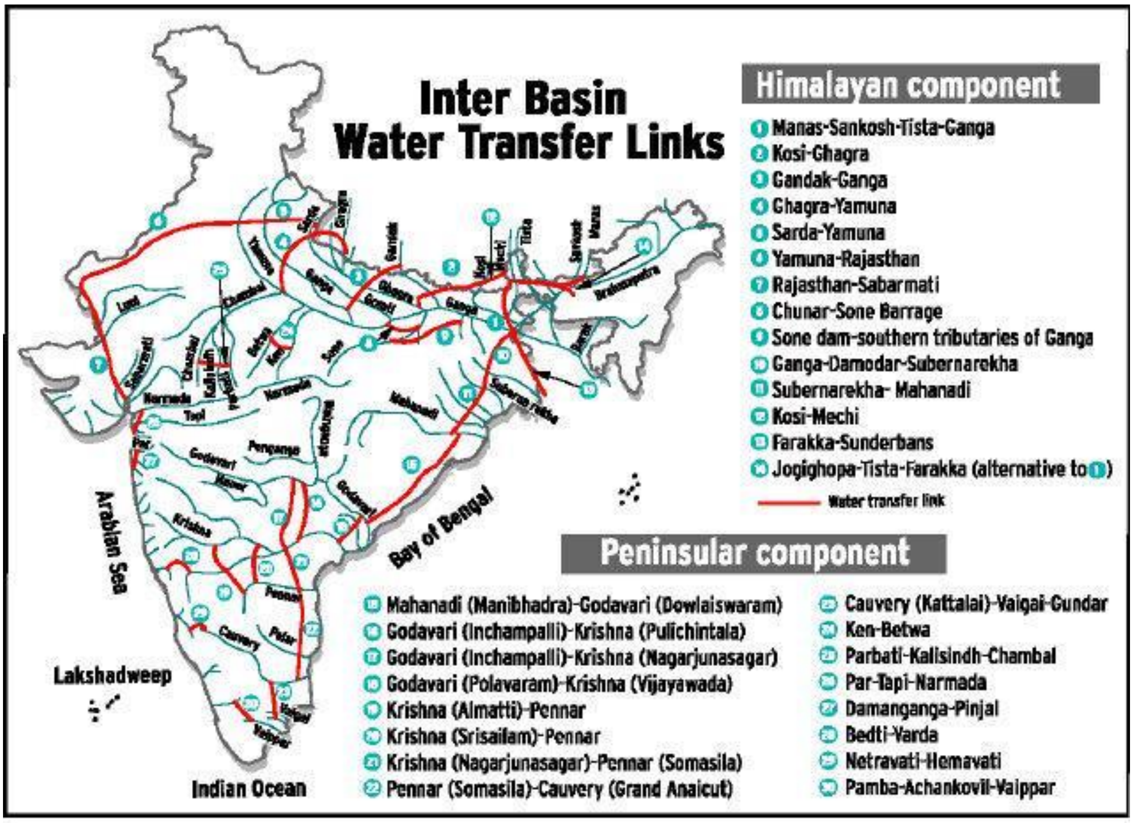

Source: National Water Development Agency

Figure 20 – Inter-linking of rivers

Ironically, rivers of northern plains have water surplus during or just after monsoon. This time Peninsular rivers also have sufficient water. While the water availability in the southern rivers may be increased, the main reason why such project is not being put to implementation is the apprehension of future water shortage in the Northern plains as a result of Climate change, whose effects are now not known. Shifting huge quantity of water would have affect on heat balance of Indian subcontinent which may affect monsoon pattern and intensity also. It will also affect the temperature and salinity of Bay of Bengal water near Bengal region.

NDA government's proposal of river interlinking met with stiff opposition from several quarters. The Supreme Court cleared the river-linking project. A group of citizens has filed review petition in the Supreme Court. Recent report of planning commission also does not support the project due to environmental and monsoon issues. Rivers linkage crosses political boundaries of states. Consensus among states is another challenge.

Linkage at small scale is feasible and few links of this river projects are under analysis or under construction. For instance, many links in Gujarat are connected. Five Peninsular links namely (i) Ken – Betwa, (ii) Parbati – Kalisindh – Chambal, (iii) Damanganga – Pinjal, (iv) Par – Tapi – Narmada & (v) Godavari (Polavaram) - Krishna (Vijayawada) have been identified as priority links for taking up their Detailed Project Reports (DPRs) by ministry of water resources in 2012. DPR of one priority link namely Ken-Betwa has been completed and was communicated to the party states. Solution envisaged in the 12thfive year plan is the water management. Locally available water needs to be managed with proper conservation techniques and by use of best available technologies in agriculture, industry with full incentive to be given for recycling of water.

4.7. National Waterways

An efficient transport sector is vital for development of the economy of any country. Compare to European countries, China etc., India has poor performance in using Inland river navigation for goods

Figure 21 – NATIONAL WATERWAYS (NWS) OF INDIA

transportation. Inland Water Transport (IWT) is a fuel efficient, environment friendly and cost effective mode of transport. Currently, there are five national waterways(NW) and sixth is being under consideration(figure 21). Following is the details of NWs:

NW1 is from Allahabad to Haldia with total length of 1620 kms. It is being used by tourism vessels, ODC carriers, IWAI vessels. Many coal based plants are located along Ganga and thus, are potential revenue source for inland navigation sector. **NW2** waterways is from Sadiya town in Assam to Dhubri at Bangladesh border with total length of 891 km. it is used by tourism vessels, Border security forces, Assam government, and private vessels. **NW3** waterway involves multiple canals on the western coast. It involves West coast canal(168km), Udyogmandal canal(23km), and Champakara canal (14km). **It** is one of the most navigable and tourism potential area in India. Raw material for fertilizer plants is major part of movement. Similarly, **NW4** waterway involves Kakinada-Puducherry canala (767km), Godavari river (171 km), and

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Krishna river (157 km). Coal on Godavari river, Cement on Krishna river and rice on both rivers, and other such food commodities are major transport on this waterway. **NW5** waterway consists of stretches such as Mahanadi Delta(101km), Brahmani and others (265km), Matai river(40km) and Geonkhali-Charbatia(217km). Coal is the major commodity on transportation here. Declaration of Barak river from **Bhanga to Lakhipur (121 km)** in the State of Assam as National Waterway is under consideration of Govt. Budget 2013 stressed on waterways connectivity for northeast India. Poor maintenance of NW is a major challenge for the government. Inland water navigation is cheaper as compared to other transport modes but does not get same level of subsidy by the government for transporting various commodities such as PDS food etc.

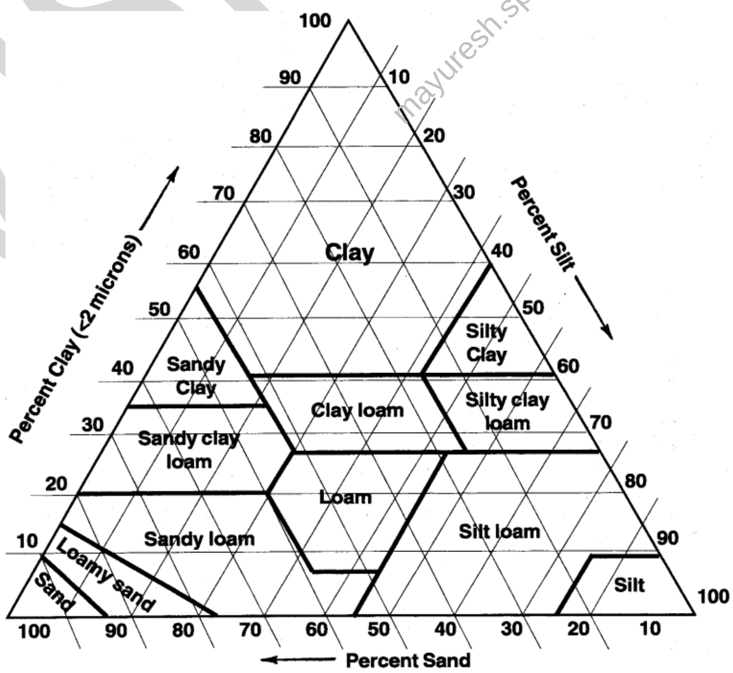
5. Soil

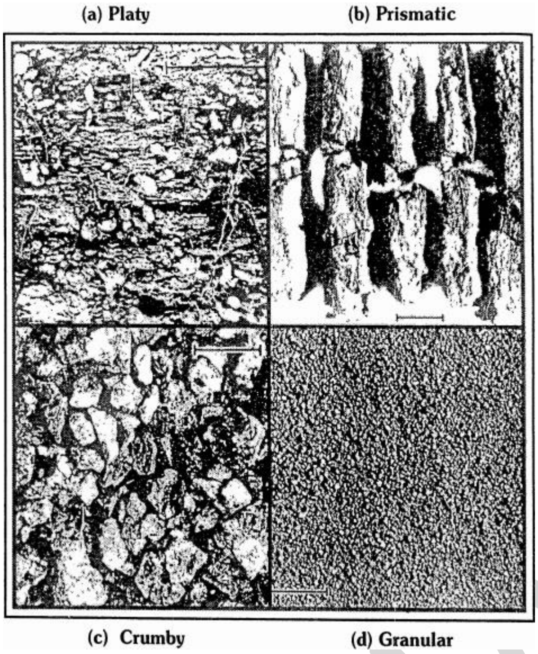
Soil constitutes a major element in the natural environment, linking climate and vegetation, and they have a profound effect on man's activities through their relative fertility. It is a valuable resource and the most important layer of the earth's crust. Soils are very much dynamic entities in which physical, chemical and biological activities are continually taking place.

5.1. Soil Properties

Soil is the mixture of rock debris and organic materials which develop on the earth's surface. It contains matter in all three states: solid, liquid and gaseous. The solid portion is partly organic and partly inorganic. The inorganic part is made up of particles derived from the parent material, the rocks which weather to form the soil. The organic portion consists of living and decayed plant and animal materials such as roots and worms. Soil water is a dilute but complex chemical solution derived from direct precipitation and from run-off, and groundwater. The soil atmosphere fills the pore spaces of the soil when these are not occupied by water. Soil atmosphere and water are present in inverse proportion to each other. The actual amounts of each of these components depend upon the type of soil.

The **Texture** of a soil refers to the sizes of the solid particles composing the soil. The sizes range from clay (less than 0.002mm) to gravel (more than 2mm). The proportions of the different sizes present vary from soil to soil and from layer to layer. Texture largely determines the water-retention properties of soil. Loam texture is best for plant growth (figure 22(i)).





(i) Soil textural classes (ii) Four basic soil structures

Figure 22 – soil texture and structure

The soil **structure** is the way the soil particles are arranged. Because of cementing action of ions in the soil, individual particles in a soil tend to aggregate together in lumps. According to the shape of the lumps, soils can be described as having a platy, prismatic, crumby and Granular structure (figure 22(ii)). The presence of humus helps the formation of a crump structure. The soil structure has an important bearing on its east of cultivation. Soils with a crumb structure are best for seed germination. Forking, raking, ploughing and harrowing are few techniques to improve the soil structure.

Soil **colloids** - tiny particles with unusual chemical properties – may be organic (very finely divided humus) or mineral (minute thin flakes called clay mineral). Together, the two types make up a clay-humus complex. Clay minerals have a vast surface area in relation to their weight and are net negatively charged. This is invariably neturalised by the attraction to their surface of positively charged ions (cations) of calcium, magnesium, potassium and sodium (bases). They are only held loosely in an exchangeable position by the clay minerals and may be given up in the process of exchange to plants in forms of nutrients which require them for growth. These cations are generally replaced by hydrogen ions. Over a period of time, this process makes soil more acid, unless the bases are replenished in some way. It is possible naturally with decomposition of animals and plants or artificially in form of fertilizer.

Soil acidity is a property related to the proportion of exchangeable hydrogen in the soil in relation to other elements. A pH value of about 6.5 is normally regarded as the most favourable for the growth of cereal crops.

Colour varies considerably in soil and can tell us much about how a soil is formed and what it is made of. In recently formed soils, the colour will largely reflect that of the parent material, but in many other cases, the colour is different from the underlying rocks. Soils can range from white to black, usually depending on the amount of humus. In cool humid areas, most soils contain relatively high humus content and are generally black or dark brown, wheras in desert or semi-desert areas, little humus is present and soils are light brown or grey. Reddish colours in soills are associated with the presence of ferric compounds and usually soil is well drained. In humid climates, grayish colours relect poor drainage conditions.

5.2. Soil Horizons

A vertical section of soil from the surface down to the bedrock consisting of many layers is collectively known as soil profile. These different sections are called soil horizons. We can easily observe different horizons in a mine or roads dug under the ground. The recognition of different soil horizons is based on the physical and chemical characteristics of soils. Scientists have divided the soil into three main horizons (figure 23). '**Horizon A'** is the topmost zone, where organic materials have got incorporated with the mineral matter, nutrients and water, which are necessary for the growth of plants. '**Horizon B**' is a transition zone between the 'Horizon A' and 'Horizon C', and contains matter derived from below as well as from above. It has some organic matter in it, although the mineral matter is noticeably weathered. '**Horizon C**' is composed of the loose parent material. This layer is the first stage in the soil formation process and eventually forms the above two layers. Underneath these three horizons is the rock which is also known as the parent rock or the bedrock.

Figure 23 – cross section of Soil profile along a tree

5.3. Soil Forming Factors

There are five main factors which controls the operation of soil processes, namely (i) parent material; (ii) topography; (iii) climate; (iv)biological activity; and (v) time. Climate and biological activity active control factors while Time, Topography and Parent Material are passive control factors. Active factors are those which supply energy that acts on the mass for the purpose of soil formation.

Parent Material

Parent material can be any in-situ or on-site weathered rock debris or transported deposits. Soil formation depends upon the texture, structure as well as the mineral and chemical composition of the rock debris. Nature, rate and depth of weathering are important considerations under parent materials. There may be differences in soil over similar bedrock and dissimilar soils

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above them. Generally young soils or the lowermost horizon shows similarity with the parent material. Ultimately, parent material's effect is seen through the texture and fertility. For instance, soils of limestone area show clear relation with the parent rock.

Topography

The influence of topography is felt through the amount of exposure of a surface to sunlight, drainage condition, and slope angle etc. In middle latitudes pole-facing slopes may have slightly different soil conditions from equator-facing slopes due to poor exposure to sunlight. Soils on hillsides tend to be much better drained than those in valleys, where gleying may take place. The susceptibility of soil to erosion increases with gradient, and soils on steep slopes are normally thinner than those on flat sites.

Climate

This factor has a major influence in governing the rate and type of soil formation, particularly through precipitation in terms of its intensity, frequency, duration; and temperature in terms of seasonal and diurnal variations. The effect of temperature is to influence the rate of chemical and biological reactions. In cool climates, bacterial action is relatively slow while in tropics, bacteria thrive. Soil of hot tropical region show deeper profiles as compared to soils of cold tundra region. Although the leaf fall in tropical forest is great, much of this is consumed and translocated down the soil profile. This is the reason why soil in tropical forests is poor in nutrients. It is the net precipitation (after subtracting evapo transpiration) that works on the soil.

Biological Activity

The vegetative cover and organism that occupy the parent materials from the start to later stages help in adding organic matter, moisture retention, nitrogen (nitrogen fixation by bacterias such as Rhizobium) etc. Dead plants provide humus. Some organic acids which form during humification aid in decomposing the minerals of the soil parent materials. Humus accumulates in cold climate as bacterial growth is low and thus layers of peat develop in sub-arctic and tundra climates.

The organisms affecting soil development range from microscopic bacteria to large mammals, including man. Besides providing much of the humus, vegetation influences the soil in several other ways. By intercepting direct rainfall and binding the soil with roots, plants check soil erosion. They counteract percolation by transpiration, reducing the effectiveness of the rainfall. They also help in maintaining the fertility of soil by brining bases (calcium, Magnesium) from the lower parts of the soil into stems and leaves, and then releasing them into the upper soil horizons. A change in vegetation may cause a change in soil.

The influence of animals on soils is both mechanical and chemical. For example, earthworms rework the soil by burrowing and also change its texture and chemical composition by passing it through their digestive systems. Equally, soil characteristics closely determine the type of animal present in the soil.

Time

Generally, the length of time the soil forming processes operate, determines maturation of soils and profile development. However, it is difficult to be precise about the role of time in soil formation, since soils vary greatly in their rates of development. On porous materials such as sandstones, soil formation is much more rapid than on impermeable materials, at least initially. On glacial hills, a few hundred years may be enough to form a soil; on dense basalt very much longer is likely to be required. Renewed evolution takes place in soils when climate or other factors change, causing the soil to adjust. In practice, many soils in mid-latitude regions are polycyclic.

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5.4. Soil Classification

Soil is not found same everywhere. A soil of one place is different from that of the other. Early classifications followed biological principles to group soils. One of the most important classifications of soils has been the zonal system. This was proposed by Russian pedologists who recognized the strong relationship between climate, vegetation and soil zones throughout the world. Three main classes of soil are recognized.

Zonal soils are those that are well developed and reflect the influence of climate as the major soil-forming factor. They can be subdivided into podzol soils, Tundra soils, brown earth, Ferralsol, Chernozem, Chestnut and Prairie soils. Sierozem of desertic and semi-desertic areas is extreme form of chestnut.

Intrazonal types are well-developed soils formed where some local factor such as parent material, terrain or age is dominant. They can be subdivided into Calcimorphic soil(on calcareous parent material), Halomorphic soils(saline), and Hydromorphic soil (marshes, swamps or poorly drained upland).

Azonal soils are those that are immature or poorly developed. It lacks a B-horizon. Thus, A-horizon likes immediately above the C-horizon of weathered parent material. This may happened because of characteristics of parent material or nature of terrain or simply the lack of time for development. It is commonplace on active flood plains, volcanic soils, newly deposited glacial drift, windblown sand, marine mud-flats. Azonal soils are subdivided into Lithosol (erosion removes soil almost as fast as it is formed on steep slopes), Regosol (dry and loose dune sands) and alluvial soils(regular supply of sediments).

5.4.1. Soil Classification in India

In ancient times, soils used to be classified into two main groups – Urvara and Usara, which were fertile and sterile, respectively. The National Bureau of Soil Survey and the Land Use Planning an Institute under the control of the Indian Council of Agricultural Research (ICAR) did a lot of studies on Indian soils. ICAR has classified Indian soils into eight types on the basis of their formation, colour, composition and location. These are described shortly below.

- **Alluvial Soil** – it is formed by rivers by depositing sediments brought from the mountains. The new alluvium is called Khadar while older deposited one is called Bangar. Khadar is renewed annually with fresh floods. Alluvial soils are most widespread in the northern plains and the covers about 40 per cent of the total area of the country. Through a narrow corridor in Rajasthan, they extend into the plains of Gujarat. In the Peninsular region, they are found in deltas of the east coast and in the river valleys. These soils are more loamy and clayey in the lower and middle Ganga plain and the Brahamaputra valley. The sand content decreases from the west to east. They are generally rich in potash but poor in phosphorous. Alluvial soils are intensively cultivated.
- **Black Soil** – it is formed from the volcanic lava. On account of high iron content and humus it is of black colour. It is also known as the Regur soil or black cotton soil. It covers most of the Deccan Plateau. In the upper reaches of the Godavari and the Krishna, and the north western part of the Deccan Plateau, the black soil is very deep. Black soil is spread over 5.18 lakh sqkm area of the country. These soils are known for their 'self ploughing' nature. The black soils are generally clayey, deep and impermeable. They swell and become sticky when wet and shrink when dried. So, during the dry season, these soils develop wide cracks. the black soil retains the moisture for a very long time, which helps the crops, especially, the rain fed ones, to sustain even during the dry season.
- **Red and Yellow Soil** – it is formed from weathering of crystalline granite (igneous rocks) and gneiss (metamorphic rocks) in areas of low rainfall in the eastern and southern part of the

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Deccan plateau. Along the piedmont zone of the Western Ghat, long stretch of area is occupied by red loamy soil. The soil develops a reddish colour due to a wide diffusion of iron in crystalline and metamorphic rocks. It looks yellow when it occurs in a hydrated form. They are generally rich in minerals like Iron, lime and potash but poor in nitrogen, phosphorous and humus.

- **Laterite Soil** – it is formed under specific monsoon conditions of climate. The dry season after rainfall is one of the speciality of monsoon climate. Under such conditions, leaching of soils is accelerated. This process reduces the silica content of rocks in soils leaving the soil rich in iron and aluminum content. Humus content of the soil is removed fast by bacteria that thrive well in high temperature. These soils are poor in organic matter, nitrogen, phosphate and calcium, while iron oxide and potash are in excess. Hence, laterites are not suitable for cultivation; however, application of manures and fertilizers are required for making the soils fertile for cultivation. Red laterite soils in Tamil Nadu, Andhra Pradesh and Kerala are more suitable for tree crops like cashewnut. Laterite soils are widely cut as bricks for use in house construction.
- **Arid Soil** – in the deserts, accelerated weathering of rocks take place on account of heating during day and cooling during night. In this type of soil mainly sand grains are found with little or no humus. In some areas, the salt content is so high that common salt is obtained by evaporating the saline water. It has also less capacity to hold moisture. Its colour varies from red to brown. Nitrogen is insufficient and the phosphate content is normal. Arid soils are characteristically developed in western Rajasthan and semi-arid type in southern Punjab and Haryana.

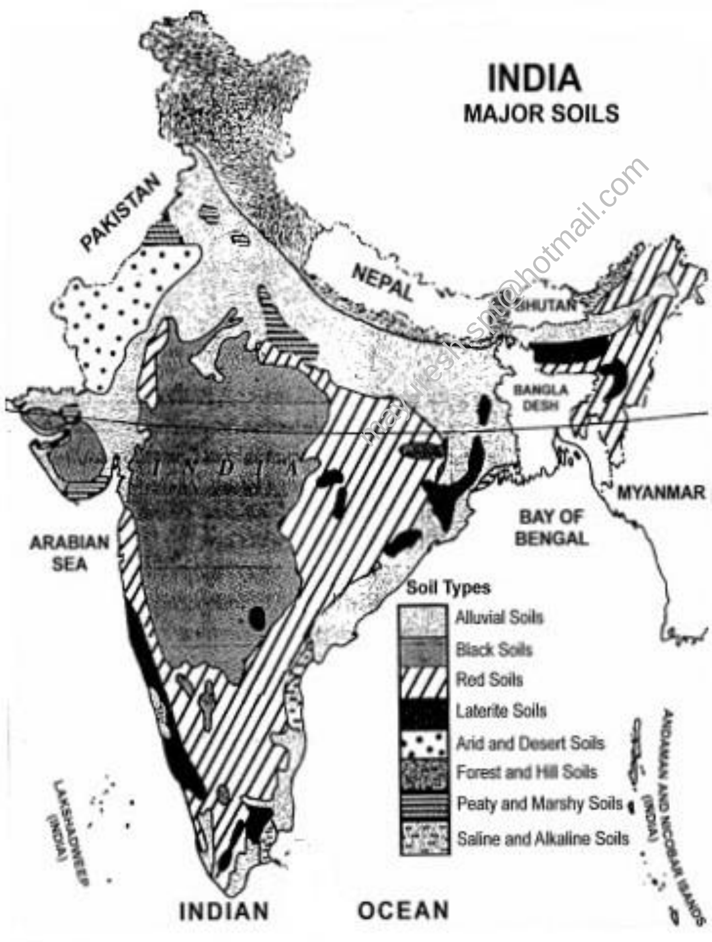

Figure 24 – Major Soil types of India

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- **Forest Soil** – it is formed in the mountain ranges of Himalayas, Purvanchal, Sahaydri etc. where sufficient rainfall is available. Soil is loamy and silty on valley sides and coarse-grained in the upper slopes. The lower valleys soil is fertile. On steep slopes, soil is very thin and less productive. This soil is spread over approximately 3 lakh sqkm area of the country.
- **Saline Soil or Usara Soil** – it contain a larger proportion of sodium, potassium and magnesium, and thus, they are infertile, and do not support any vegetative growth. They have more salts, largely because of dry climate and poor drainage. Their structure ranges from sandy to loamy. They lack in nitrogen and calcium. They are found in arid and semi-arid regions, western Gujarat, deltas of the eastern coast and in Sunderban areas of West Bengal. Seawater intrusions in the deltas promote the occurrence of saline soils. In the areas of intensive cultivation with excessive use of irrigation, especially in areas of green revolution, the fertile alluvial soils are becoming saline. In such areas, especially in Punjab and Haryana, farmers are advised to add gypsum to solve the problem of salinity in the soil.
- **Peaty and Marshy Soil** – it is found in areas of heavy rainfall and high humidity such as Kerala, Odisha, Bengal, Coastal areas of Tamil Nadu. Large quantity of dead organic matter accumulates in these areas, and this gives a rich humus and organic content to the soil. Organic matter in these soils may go even up to 40-50 per cent. The vegetation grows very dense in these areas. At many places, they are alkaline also due to presence of salt.

5.5. Soil Degradation

In simple terms, soil degradation is defined as the decline in the soil quality or the soil fertility. It can happen either by declining share of nutrients or low population of micro-organism in the soil such as earthworms or change in soil structure or change in pH (alkinity) or addition of toxic elements and pollutants etc. For instance, animals walking on the land or human removing upper layers of soil may results into soil degradation. Soil degradation is the main factor leading to the depleting soil resource base in India. The degree of soil degradation varies from region to region according to the topography, wind, precipitation and anthropogenic factors. Soil degradation includes soil erosion, physical deterioration, chemical deterioration and biological deterioration.

5.6. Soil Erosion

It is the removal of soil at a greater rate than its replacement by natural agencies. Soil forming and erosional processes go on simultaneously. When the balance between these two different processes is disturbed by natural or human factors, result into net removal of soil. Some soil erosion occurs without the intervention of human activities but the latter often accelerates the natural processes, e.g. vegetation clearance, over-grazing, some land-drainage schemes. Problem of soil erosion increases with pressure of increasing population on the land. Natural vegetation is cleared for agricultural, pastoral and construction activities.

Topography, rainfall, wind, lack of vegetation cover, land use practices etc. are the causes of soil erosion. The rugged topography and steep slopes affect soil erosion rate through its morphological characteristics. Two of these, namely gradient and slope length, are essential components in quantitative relationships for estimating soil loss. Erosion increases dramatically because the increased angle facilitates water flow and soil movement.

Two main elements of climate – **wind and rainfall** – are powerful agents of soil erosion. Erosive processes are set in motion by the energy transmitted from either rainfall or wind or a combination of these forces. Wind erosion is significant in arid and semi-arid regions. Regions with heavy rainfall have dominance of water in erosional processes. Removal may be in the form of splash erosion, Sheet wash, Rill erosion, gullying erosion (figure 25). Splash erosion is the first stage in soil erosion and it occurs when raindrop hit bare soil. Sheet erosion, takes place on level of lands after a heavy shower, removes finer and fertile top soil. Gullies cut the

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agricultural lands into small fragments and make them unfit for cultivation. Chambal region of central India is infamous for its ravines (large number of deep gullies).

Figure 25 – Gully erosion

The lowest soil erosion rate is found in undisturbed forests. However, once forest land is converted to agriculture, erosion rates increase because of **vegetation** removal, over-grazing, and tilling. Vegetation cover reduces erosion. Living and dead plant biomass reduces soil erosion by intercepting and dissipating raindrops and wind energy. Plant roots physically bind particles, thus stabilising the soil and increasing its resistance to erosion. The uptake of water by plant roots also depletes the soil water content and thereby further increases infiltration rates.

Land use practices such as agricultural and pastoral activities are causes of soil erosion. Croplands are vulnerable because the soil is repeatedly tilled and left without a protective cover of vegetation. Excessive grazing by animals lead to poor vegetation cover and thus, enhances wind and water-led soil erosion processes. Over-irrigation results into removal of top nutrient soil with excess water. It also brings salts to the surface and destroys fertility. Without proper humus, addition of chemical fertilizer hardens the soil.

5.7. Soil Management

Soil management is not a single and straight process. It concerns all operations, practices that are used to maintain the quality of soil. If soil erosion and exhaustion are caused by humans; by corollary, they can also be prevented by humans. Soil erosion is essentially aggravated by faulty practices. For instance, recommended ratio of nitrogen, phosphorus and potassium (NPK) fertilizer in India is 4:2:1 but actual usage is in the ration of 10:4:1. Lands with a slope gradient of 15 - 25 per cent should not be used for cultivation. If at all the land is to be used for agriculture, terraces should carefully be made.

Over-grazing and shifting cultivation are other major faulty practices. It should be regulated and controlled by villagers collectively. Contour bunding, Contour terracing, check dams, regulated forestry, cover cropping, mixed farming and crop rotation are some other sustainable methods to manage soil quality. In arid and semi-arid areas, shelter belts or green belts should be constructed around the cultivable land to protect them from progressive sand dunes.

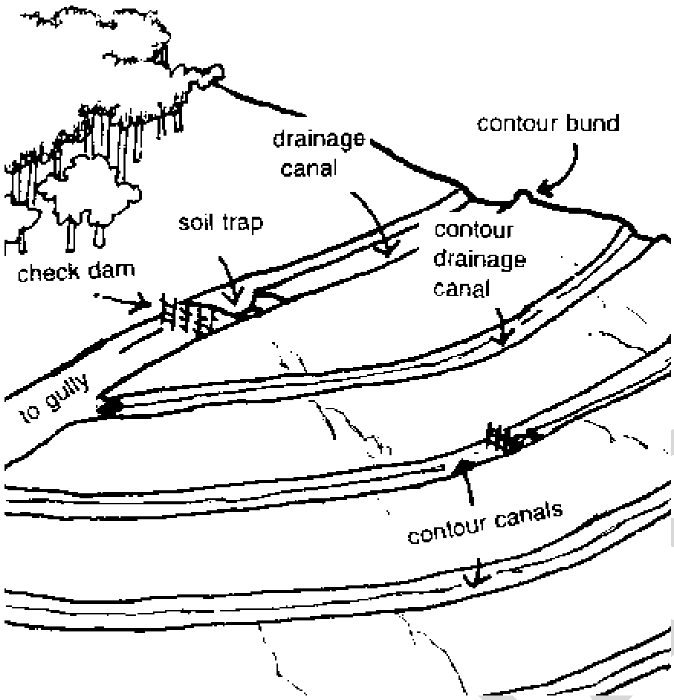

Figure 26 – soil management techniques

The Central Soil Conservation Board, set up by the Government of India, has prepared a number of plans for soil conservation in different parts of the country. These plans are based on the climatic conditions, configuration of land and the social behaviour of people.

Centrally sponsored scheme entitled "National project on management of soil health and fertility (NPMSF)" has been formulated by the centre in 2008-09. It aims to facilitate and promote Integrated Nutrient Management (INM) through judicious use of chemical fertilizers in conjunction with organic fertilizers. It also aims to strengthen soil testing facilities by installing more soil testing laboratories. One of the components is to build up capacity through training of farmers and field demonstration etc. Project also envisages preparing database for balanced use of fertilizer, which is site specific. Other project/missions such as National Mission on Sustainable Agriculture (NMSA), National project on promotion of organic farming, Mahatma Gandhi national rural employment guarantee act (MGNREGA), soil and land use survey projects of centre etc. have bearing on managing the quality of soil.

Student Notes:

COMPOSITION AND STRUCTURE OF THE ATMOSPHERE

Contents

1. Composition of the Atmosphere

In general, atmosphere is a layer of gases and dust surrounding a planet that is held in place by the gravity of the planet body. An atmosphere is more likely to be retained if the gravity is high and the atmosphere's temperature is low. In fact, earth's atmosphere makes earth unique in the solar system. Planet Earth's atmosphere is best suitable for life and thus, it is important to understand the composition as well as structure of it. In this context, man has started studying the atmosphere thousands of years before. The Rig Vedic verses have mention of Monsoon, seasons etc.

Earth's atmosphere is composed of gases, water vapours and dust particles. Although other important properties of the atmosphere such as temperature and pressure, can vary considerably in both time and space, its composition in terms of the relative proportions of the gases present in any unit volume, tends to remain remarkably constant. Thus, the atmosphere generally tends to act very much as a single gas, which we commonly known as 'air'. The horizontal variation in the per cent share of these components of atmosphere has less variation as compare to vertical variation.

1.1. Gases

The main component gases of dry air are listed in Table 1. It should be noticed that nitrogen and oxygen together make up about 99 per cent of the volume, and that the other one per cent is chiefly Argon. Other gases such as Methane, Ozone are found in traces.

Constituent gas	Percentage volume
Nitrogen	78.08
Oxygen	20.95
Argon	0.93
Carbon dioxide	0.036
Neon	0.002
Helium	0.0005
Krypton	0.001
Xenon	0.00009
Hydrogen	0.00005

Table 1 – Average composition of dry air

Nitrogen does not easily enter into chemical union with other substances, but it is an important constituent of many organic compounds. Atmospheric nitrogen acts as a reservoir pool for nitrogen cycle. Nitrogen fixing organisms such as Rhizobium use free nitrogen of the atmosphere to convert it to usable form such as nitrates.

Oxygen is an important part of the atmosphere and is necessary to sustain terrestrial life as it is used in respiration. It is also used in combustion. It is believed that first oceans got saturated with oxygen and after that it started flowing into the atmosphere. Source of oxygen is plants with photosynthesis. Mountain climbers sometime require oxygen cylinders due to low concentration of oxygen at greater heights.

Argon is an inert gas. Argon extracted from the atmosphere is used for industrial purposes such as bulb manufacturing, welding equipments etc.

Carbon dioxide is released from the earth's interior, respiration, soil processes, deforestation, and combustion. Carbon dioxide is meteorologically a very important gas as it is transparent to the incoming solar radiation but opaque to outgoing terrestrial radiations. It absorbs a part of terrestrial radiation and reflects back some part of it towards the earth's surface. It is largely responsible for the greenhouse effect.

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Ozone is another important constituent of atmosphere. Ozone is made up of three atoms of oxygen when three molecules of oxygen gas convert into two molecules of Ozone using sun's high energy radiations. It is found in very small quantity (0.00005 per cent by volume) in the upper atmosphere, 15-50km above the earth's surface. Maximum concentration is found at the height of 15-35km. It protects the life on earth by absorbing ultra-violet rays radiating from the sun and prevents them from reaching the surface of the earth. In the absence of the ozone layer, high energy ultra-violet rays would have made earth unfit for habitation.

1.2. Water Vapour

Table 1 refers to the average constituents of dry air. The lower parts of the atmosphere, up to 10-15 km, contain in addition water vapour, which is largely derived by evaporation from water bodies on the earth and by transpiration from plants. It is one of the 'most variable' components of the atmosphere. It decreases with altitude and not found at great heights because mixing and turbulence is not sufficiently strong to carry it up very far. In the warm and wet tropics, it may account for 4% of the air by volume, while in the dry and cold areas of desert and polar regions, it may be less than 1% of the air. Water vapour also decreases from the equator towards the poles.

Water vapour, too, is capable of absorbing heat and acts like a blanket allowing the earth neither to become too cold nor too hot. Water vapour is fundamental to many essential meteorological processes, such as rain-making. It is source of all clouds and precipitation. In the condensation process, vast amount of energy is released in form latent heat of condensation, ultimate driving force for most of the storms.

The actual amount of the water vapour present in the atmosphere is known as the **absolute humidity**. It is the weight of water vapour per unit volume of air. The absolute humidity differs from place to place on the surface of the earth. The percentage of moisture present in the atmosphere as compared to its full capacity at a given temperature is known as the **relative humidity**. It is greater over the oceans and least over the continents. The air containing moisture to its full capacity at a given temperature is said to be **saturated**. Moisture holding capacity of the air is directly proportional to its temperature.

1.3. Dust Particles

The atmosphere also carries in suspension variable amounts of solid material in the lower layers of atmosphere. Convectional air currents may transport them to great heights. The higher concentration of dust particles is found in subtropical and temperate regions due to dry winds in comparison to equatorial and polar regions. The term 'dust particles' includes all the solid particles present in the air except the gases and water vapour. It includes sea salts, fine soil, smoke-soot, ash, pollen, dust and disintegrated particles of meteors and originates from different sources.

Dust particles provide the necessary nuclei on which water vapour can condense to form **clouds** and eventually precipitation. Condensation on these fine particles near the surface causes formation of **fog**. Large amount of dust tend to make the atmosphere hazy, and in extreme cases, where pollution is involved, dust particles can be positively harmful to health. By the process of **scattering**, dust particles contribute to the varied colours of red and orange at sunrise and sunset. The blue colour of the sky is also due to selective scattering by dust particles. The duration of twilight is also affected by the presence of these dust particles in the air.

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1.4. Changes in the Atmosphere

Since industrial revolution, human activities have caused various changes into earth's atmosphere. We look at four very different atmospheric changes here.

1.4.1. Air Pollution

Air pollution is the introduction of chemicals, particulates, biological materials or other harmful materials into the earth's atmosphere. These pollutants can be solid particles, liquid, and gases. Major pollutants are carbon oxides (CO_x), Nitrous Oxides (NO_x), Volatile organic compounds, particulates, sulphur dioxide, Toxic metals such as lead and mercury etc. Many of these are new compounds in the atmosphere which have changed the composition to negligible level but their presence throws challenges for humans. It causes damage, disease and death of humans and other living organisms or infrastructure. Air pollution causes respiratory infections, heart disease, and lung cancer etc. Major sources of these pollutants involves vehicular emission, power plants, industries, waste incinerators, agricultural practices, fumes, waste deposition etc.

Acid rain is the result of increased pollutants in the atmosphere. Rain water is naturally acidic due to atmospheric carbon dioxide which makes weak acid with rain water. Acid rain is caused by other gases released when fossil fuels are burnt. Two gases are the main culprits: **Sulphur dioxide** (forms sulphuric acid) and **Nitrogen oxides** (forms nitric acid). These increase the acidity of rainwater. The dilute acid falls to ground as acid rain which causes the following problems:

- Lakes become acidic and plants and fishes die as a result
- Tree growth is damaged, whole forests can die as a result
- Acid rain attacks metal structures and also buildings made of limestone

1.4.2. Global Warming

In very cold regions, glass houses are constructed for growing vegetables. These are known as **Greenhouses**. In these houses, glass covering allows short wavelength sunrays to enter but does not allow it to be radiated back to atmosphere. At atmospheric level, the greenhouse gases do not allow thermal radiation from a planetary surface (long waves) to pass and re-radiate them in all directions. Since part of this re-radiation is back towards the surface and the lower atmosphere, it results in an elevation of the average surface temperature above what it would be in the absence of the gases. Major **greenhouse gases** are: carbon dioxide, methane, nitrous oxide, water vapour and Ozone.

With increase in the percentage of greenhouse gases, it is believed that temperature of earth is increasing dramatically. This is termed as global warming. Main contributor for this rise in temperature is **carbon dioxide (**CO_2**)**. The scientists have observed that CO_2 is largely contributed from burning of fossil fuels. The burning of fossil fuels and extensive clearing of native forests has contributed to a 40% increase in the atmospheric concentration of carbon dioxide, from 280 to 392 parts per million (ppm) in 2012.

Other gases such as Methane, water vapour, Nitrous oxide, Hydroflurocarbons (HFCs), Perflurocarbons (PFCs), Sulphur hexafluoride (SF_6) are playing considerable role in global warming. SF_6, PFCs etc. are present only in traces but their life span and greenhouse potency is very high. For instance, SF_6 is the most potent greenhouse gas in existence. With a global warming potential 23,900 times greater than carbon dioxide, one pound of SF_6 has the same global warming impact of 11 tons of carbon dioxide. It is also very persistent in the atmosphere with a lifetime of 3,200 years. SF_6 is widely used in circuit breakers, gas-insulated substations, and other switchgear to manage the high voltages.

Global warming would adversely affect the ecosystem on the Earth and the weather patterns around the world in the following ways:

- Melting of ice at polar regions and glaciers on high mountains. It would increase the sea level.
- Many climatic and weather events are expected to change drastically. Recent examples of extreme temperature, precipitation are associated with the global warming.
- Global warming would change the habitats of organism. Those unable to adjust to these rapid changes may not be able to survive.

1.4.3. Ozone Depletion

The release of chemical compounds such as Chlorofluorocarbons (CFCs) from earth into the atmosphere poses a serious threat to ozone layer. CFCs are synthetic industrial chemical compounds containing chlorine, fluorine, and carbon atoms. CFCs are widely used as cooling fluids in the refrigerating systems. CFCs when released in air are transported by the vertical atmospheric circulation and reach the ozone layer in the stratosphere. The CFCs absorb the ultra-violet radiation and decompose to chlorine oxide molecules and can convert the ozone into ordinary oxygen molecules. A study of the ozone layer based on data provided by the satellites, showed a substantial decline in the total ozone gas. The scientists have discovered a hole in the ozone layer over the continent of Antarctica. CFCs are transported to Antarctica region by atmospheric wind systems. Here, CFCs get trapped in the Antarctica cold air by polar vortex[1] and deplete ozone layer.

1.4.4. Ozone Pollution

Ozone occurs at ground-level naturally in low concentrations. The two major sources of natural ground-level ozone are hydrocarbons, which are released by plants and soil, and small amounts of stratospheric ozone, which occasionally migrate down to the earth's surface. Neither of these sources contributes enough ozone to be considered a threat to the health of humans or the environment. But the ozone that is a byproduct of certain human activities does become a problem at ground level. With more automobiles, and more industry, there's more ozone in the lower atmosphere. Tropospheric ozone is formed by the interaction of sunlight, particularly ultraviolet light, with hydrocarbons and nitrogen oxides, which are emitted by automobiles, gasoline vapors, fossil fuel power plants, refineries, and certain other industries.

High ozone levels usually occur during the warm, sunny summer months (from May through September). Typically, ozone levels reach their peak in mid to late afternoon. A hot, sunny, still day is the perfect environment for ozone pollution production.

Near the earth's surface, ozone molecules damages forests and crops; destroys nylon, rubber, and other materials; and injures or destroys living tissue. It is a particular threat to people who already have respiratory problems.

2. Structure of the Atmosphere

It is the lower part of the atmosphere which has interested man from times immemorial. But from the beginning of the 20th century, when aeroplanes and radio waves were invented, the knowledge of the upper part of the atmosphere became rather essential. The earth's atmosphere consists of zones or layers arranged like spherical shells according to altitude above earth's surface. Each zone has a unique set of characteristics. For the most part the layers are

[1] The stratospheric polar vortex is a large-scale region of air that is contained by a strong west-to-east jet stream that circles the polar region.

not at all sharply defined, and their boundaries are arbitrarily established. The density, temperature and composition of the atmosphere varies with altitude. Density is highest near the surface of the earth and decreases with increasing altitude. The temperature changes differently in different layers. Heavy gases such as Oxygen exist near the surface. At greater heights, the lightest gases do in fact separate out, forming several concentric gas envelopes around the Earth.

The atmosphere is divided into the five different layers depending upon the **temperature condition**. They are: troposphere, stratosphere, mesosphere, thermosphere and exosphere.

2.1. Troposphere

Troposphere is the lowermost layer of the atmosphere. Its average height is 13 km and extends roughly to a height of 8 km near the poles and about 18 km at the equator. It is thickest at the equator because strong convection currents transport heat to such great heights. It contains 75 per cent of the total gaseous mass of the atmosphere. This layer contains dust particles and water vapour also. The temperature in this layer decreases at the rate of 1°C for every 165m of height (or at a mean rate of 6.5 degree C /km).The decrease occurs because air is compressible and its density decreases with height allowing rising air to expand and thereby cool. It is interesting to note that the lowest temperature in the entire troposphere is found over the equator and not at the poles. The air temperature at the top of troposphere is about minus 80^{0}C over the equator and about minus 45^{0}C over the poles.

Word 'troposphere' is derived from the Greek word 'tropos' meaning 'mixing'. Troposphere is marked by turbulence and eddies. It is also called the convective region, for all the convective cease at the upper limit of the troposphere. All changes in climate and weather take place in this layer. Clouds formation, thunderstorms etc. occur in this layer. Wind velocity increase with height and attain the maximum at the top.

At the top of the troposphere there is a shallow layer separating it from the next thermal layer of the atmosphere. This shallow layer is known as the **tropopause**. Tropopause has its greatest height near the equator. In the middle and high latitudes, the height of the tropopause varies according to seasons. For example, at latitudes 45N&S the average height of the tropopause in January is about 12.5 km while in July it becomes 15 km.

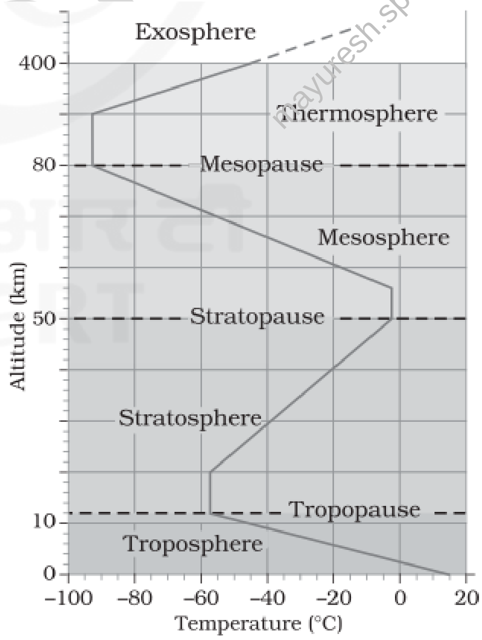

Figure 1 – Structure of atmosphere on the basis of temperature

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2.2. Stratosphere

The stratosphere is found above the tropopause and extends up to a height of 50 km. The lower stratosphere is isothermal in character. This temperature region is found to be present up to about 20 km and after this temperature rises. In summers, the increase in the stratospheric temperature with latitudes continues upto the poles. But during the winter season the stratosphere is warmest between latitudes $50^0 - 60^0$. Onwards, temperature decreases again. The thickness of the stratosphere is highest at the poles.

This layer is free of any clouds of weather changes. It is an ideal place for flying of big planes. At about 50 km, temperature begins to fall. This is end of stratosphere, and is called the **stratopause**.

The portion of the stratosphere having maximum concentration of ozone is called **ozonosphere**. The rise in temperature with height in stratosphere is because of the absorption of ultra-violet by the ozone gas. Details of ozone gas are already discussed above.

2.3. Mesosphere

The mesosphere lies above the stratopause, and extends up to a height of 80 km from 50km. In this layer, once again, temperature starts decreasing with the increase in altitude and reaches up to minus 100° C at the height of 80 km. It is the coldest layer in the atmosphere. The exact upper and lower boundaries of the mesosphere vary with latitude and with season, but the lower boundary of the mesosphere is usually located at heights of about 50 km above the Earth's surface and the mesopause is usually at heights near 100 km. In summers, the height of mesosphere descends down to 85km at middle and high latitudes. The upper limit of mesosphere is known as the **mesopause**.

2.4. Thermosphere

The thermosphere is located between 80 and 400 km above the mesopause. In this layer the temperature increases rapidly with increase in height. It is estimated that the temperature reaches 1500 degree C. The air is so thin that a small increase in energy can cause a large increase in temperature. Because of the thin air in the thermosphere, scientists can't measure the temperature directly. They measure the density of the air by how much drag it puts on satellites and then use the density to find the temperature.

The Earth's thermosphere also includes the region called the **ionosphere.** It contains electrically charged particles known as ions, and hence, it is known as ionosphere. Ionization of molecules and atoms occurs mainly as a result of ultra-violet, x-rays and gamma radiations. The high temperatures in the thermosphere also cause molecules to ionize. This is why an ionosphere and thermosphere can overlap.

Radio waves transmitted from the earth are reflected back to the earth by this layer. This layer also protects the earth from meteorites and remains of abandoned satellites. They are burned and reduced to ashes due to high temperature as they enter this layer.

Ionosphere also includes some parts of mesosphere and exosphere. Ionosphere is further divided into different layers, namely D-layer (upto 99km), E-layer (90-130km), Sporadic E-Layer, F1 & F2 layer (150-380km) and G-layer (>400km). Layers such as D-layer, E-layer, exist only during day time and vanishes as soon as sun sets.

2.5. Exosphere

The uppermost layer of the atmosphere above the thermosphere is known as the exosphere. This is the highest layer but very little is known about it. It lies beyond 400km to 1000s of kms where it merges with outer space. At such great height the density of atoms is extremely low. It

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is largely home to Helium and Hydrogen. Temperature increases with height and may cross 5000^{0}C.

Stratification of atmosphere can also be done on the basis of **chemical composition**. According to International Space Symposium 1962, atmosphere can be divided into two broad layers, namely **Homosphere** and **Heterosphere**. Former is the lower layer and extends up to 88km from the earth's surface. The proportions of the component gases are uniform at different levels. The three main-sub divisions of Homosphere are troposphere, stratosphere and mesosphere. Heterosphere extends beyond 88 km to more than 3500 km. Here, atmosphere is not uniform in its composition. It is also referred to as thermosphere as temperature rises with height. In this sphere, gases are arranged in roughly spherical shells. The innermost of these is a Nitrogen layer, found at heights between 100 and 200km; this is succeeded in turn by layers of Oxygen (200-1100km) and Helium (1100-3500km); and finally beyond 3500km only Hydrogen exists.

Student Notes:

INSOLATION, EARTH'S HEAT BALANCE, DIFFERENT ATMOSPHERIC CIRCULATIONS – GLOBAL WINDS, CYCLONES

Contents

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1. Insolation

The earth's atmosphere is very much a **dynamic** entity. Large volumes of air are continually being moved both up and down and across the face of the Earth. As a proof, we feel air when it is in motion. There must be some energy involved here. It needs to be understood that the atmosphere is not a closed system. It is in contact with both the earth and with space, and receives energy from both directions. However, Earth itself directly contributes only a negligible amount of energy to the atmosphere, and its main role is to reflect energy from elsewhere. The ultimate sole source of atmospheric energy is in fact **heat and light received through space from the Sun**. This energy is known as **solar insolation.**

The Earth receives only a tiny fraction of the total amount of Sun's radiations. Only **two billionths** or two units of energy out of 1,00,00,00,000 units of energy radiated by the sun reaches the earth's surface due to its small size and great distance from the Sun. The unit of measurements of this energy is **Langley** (Ly). On an average the earth receives 1.94 calories per sq. cm per minute (2 Langley) at the top of its atmosphere.

1.1. Factors Influencing Insolation

The insolation received on earth is not same everywhere. The amount and the intensity of insolation vary from place to place, during a day, in a season and in a year. The factors that cause these variations in insolation are:

1. **Revolution of earth around sun:** earth revolves in an elliptical orbit around the sun. Thus, distance between the Sun and the earth vary. The earth is farthest from the sun on 4th July. This position of the earth is called **aphelion**. On 3rd January, the earth is the nearest to the sun. This position is called **perihelion**. Therefore, the annual insolation received by the earth at perihelion is slightly more than the amount received at aphelion. 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 insolation does not have great effect on daily weather changes on the surface of the earth.
2. **The rotation of earth on its axis:** earth rotates around its axis and makes an **angle of 66½** with the plane of its orbit round the sun. This particular characteristic of earth **has great amount of influence** on the amount of insolation received at different latitudes. The seasons in each hemisphere are dictated not by the closeness to the sun but by the axial tilt of the earth.
3. **The angle of inclination of the sun's rays:** Since the earth is round, the sun's rays strike the surface at different angles at different places. The angle formed by the sun's ray with the tangent of the earth's circle at a point is called **angle of incidence**. It influences the insolation in two ways as follows:
   - When the sun is almost overhead, the rays of the sun are vertical. The **angle of incidence** is large. Hence, they are concentrated in a smaller area, giving more amount of insolation at that place. If the sun's rays are oblique, angle of incidence is small and sun's rays have to heat up a greater area, resulting in less amount of insolation received there.

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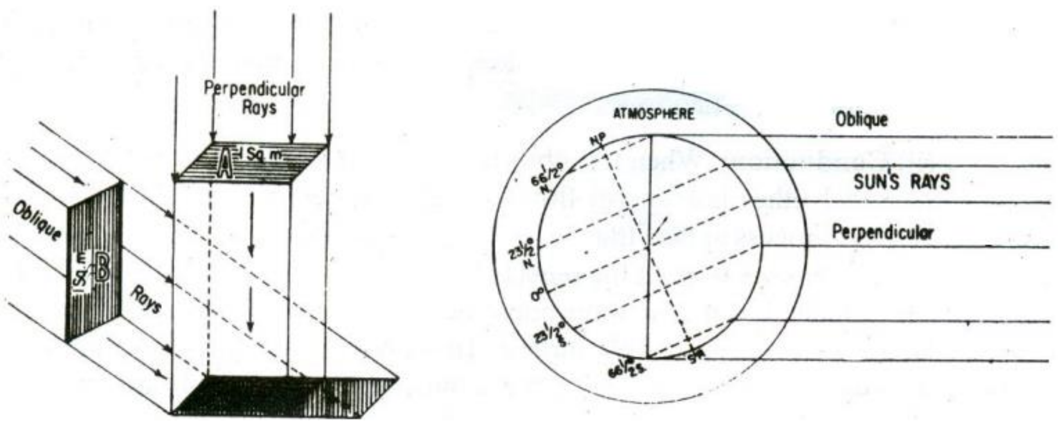

Figure 1 – effect of angle of inclination on Insolation

- The sun's rays with small angle **traverse more of the atmosphere** than rays striking at a large angle. Longer the path of sun's rays, greater is the amount of reflection and absorption of heat by atmosphere. As a result the intensity of insolation at a place is less (figure 1). Angle of inclination of solar radiation depends on latitude of a place. The higher the latitude the less is the angle they make with the surface of the earth resulting in slant sun rays. Figure 1 show the winter Solstices in the Northern Hemisphere where angle of inclination is zero at 66 ½ N latitude.

Latitude	0°	20°	40°	60°	90°
December 22 (winter solstice)	12h 00m	10h 48m	9h 8m	5h 33m	0 m
June 21(summer Solstice)	12h	13h 12m	14h 52m	18h 27m	6 months

Table 1 – Length of Day on winter and summer Solstices in the Northern Hemisphere

4. **The length of the day:** the duration of day is controlled partly by latitude and partly by the season of the year. The amount of insolation has close relationship with the length of the day. It is because insolation is received only during the day. Other conditions remaining the same, the longer the days the greater is the amount of insolation. In summers, the days being longer the amount of insolation received is also more. As against this in winter the days are shorter the insolation received is also less. On account of the inclination of the earth on its axis at an angle of 23 ½ ^{0}, rotation and revolution, the duration of the day is not same everywhere on the earth. At the equator there is 12 hours day and night each throughout the year. As one moves towards poles duration of the days keeps on increasing or decreasing. It is why the maximum insolation is received in equatorial areas. Table 1 show the duration of day (in hours & minutes) on winter and summer solstices in the Northern hemisphere.
5. **The transparency of the atmosphere:** The earth's atmosphere is more or less transparent to short wave solar radiation which has to pass through the atmosphere before striking the earth's surface. The transparency depends upon cloud cover, its thickness, water vapour and solid particles, as they reflect, absorb or transmit insolation. High energy ultra-violet rays are absorbed by the **Ozone layer**. **Thick clouds** hinder the insolation to reach the earth while clear sky helps it to reach the surface. **Water vapour** absorbs insolation, resulting in less amount of insolation reaching the surface. Very **small-suspended particles** in the troposphere scatter visible spectrum both to the space and towards the earth surface.
6. **Solar variation:** It is the change in the amount of radiation emitted by the Sun. These variations have periodic components, the main one being the approximately 11-year sunspot cycle. **Sunspots** are temporary phenomena on the photosphere of the Sun that appear visibly as dark spots compared to surrounding regions. When there is an increase in sun spots it leads to increase[1] in the amount of solar radiation. But this change is almost negligible.

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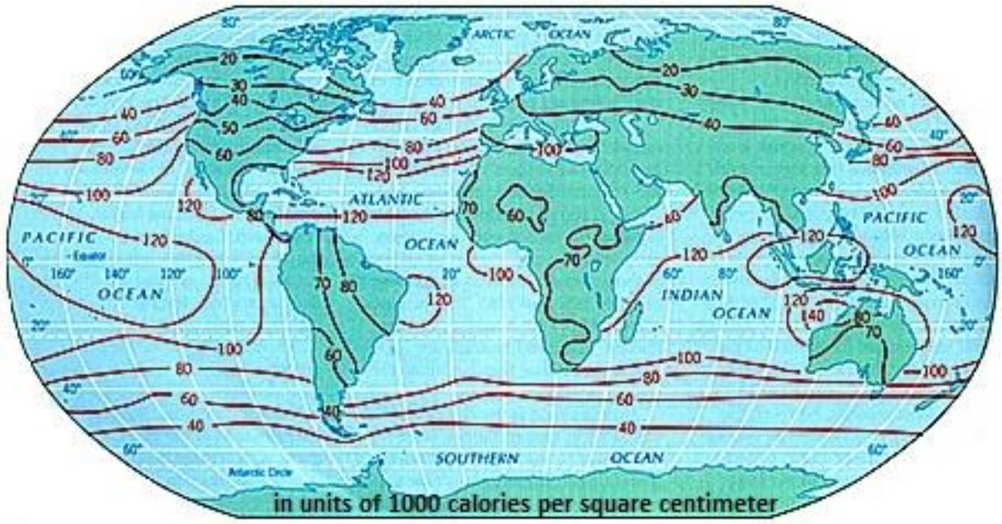

Figure 2 – average annual insolation on the surface of the earth

7. **Topographical variations:** Earth does not have a featureless surface. The topographical variations are the major factors modifying the distribution of insolation. Variability in elevation, surface orientation (slope and aspect), and obstruction by surrounding topographic features creates strong local gradients of insolation. Similarly, in the northern hemisphere a south-facing slope (more open to sunlight and warm winds) will therefore generally be warmer and dryer due to higher levels of evapotranspiration than a north-facing slope.[1] This can be seen in the Swiss Alps, where farming is much more extensive on south-facing than on north-facing slopes. In the Himalayas, this effect can be seen to an extreme degree, with south-facing slopes being warm, wet and forested, and north-facing slopes cold, dry but much more heavily glaciated. Vegetation, human activities are more visible on the slopes where insolation is more relatively.

Under combined effect of the above discussed factors, the amount of total annual insolation received by different regions is different. The insolation received at the surface varies from about 320 Watt/m^2 in the tropics to about 70 Watt/m^2 in the poles. Maximum insolation is received over the subtropical deserts. **Equator receives comparatively less insolation than the tropics** due to presence of clouds. Generally, at the same latitude the insolation is more over the continent than over the oceans because more clouds over the oceans reflect sun rays back into space. **Isohels** are lines connecting points on the earth surface that receive equal amounts of sunshine. Isohels are more or less parallel to latitudes, especially in southern hemisphere (figure 2).

1.2. Heating and Cooling of the Atmosphere

Sun is the ultimate source of the atmospheric heat and energy, but its effect is not direct. For example, as we climb a mountain or ascend in the atmosphere, temperature become steadily lower, rather than higher, as we might expect. This is because the mechanism of heating the atmosphere in not simple. Four common types of energy transport are involved in heating of the atmosphere (figure 3). They are:

1. **Radiation:** it is the process where transference of heat is directly from space to atmosphere through electromagnetic radiations[2]. Photon[3] particles in the radiations collide with the air molecules in the atmosphere and transfer energy in this process. All objects whether hot or cold emit radiation continuously. The wavelength at which a body radiates depends on its surface temperature. The shorter the wavelength, higher the energy carried by the radiations The sun, having an extremely hot surface temperature, radiates fairly short wavelengths, part of which is felt as warmth, part of which are visible as light. The Earth, on

the other hand, having a cool surface, re-radiates heat at much longer wavelengths. The re-radiate heat from the earth is called **Terrestrial radiation**. Atmosphere is transparent to short waves and opaque to long waves. The long wave radiation is absorbed by the atmospheric gases particularly by carbon dioxide and the other green house gases. Hence energy leaving the earth's surface heats up the atmosphere more than the incoming solar radiation.

2. **Conduction:** When two objects of unequal temperature come in contact with each other, heat energy flow from the warmer object to the cooler object and this process of heat transfer is known as conduction. The flow continues till temperature of both the objects becomes equal or the contact is broken. The conduction in the atmosphere occurs at zone of contact between the atmosphere and the earth's surface by terrestrial radiations. However, this is **a minor method** of heat transfer in terms of warming the atmosphere since it only affects the air close to the earth's surface. This is because of the fact that the air is poor conductor of heat[4].
3. **Convection:** In this process, energy is transferred through motion of molecules itself. The air in contact with the earth rises vertically on heating in the form of currents and further transmits the heat of the atmosphere. The heating of the air leads to its expansion. Its density decreases and it moves upwards. Continuous ascent of heated air creates vacuum in the lower layers of the atmosphere. As a consequence, cooler air comes down to fill the vacuum. This process of vertical heating of the atmosphere is known as convection. The convective transfer of energy is confined only to the troposphere.

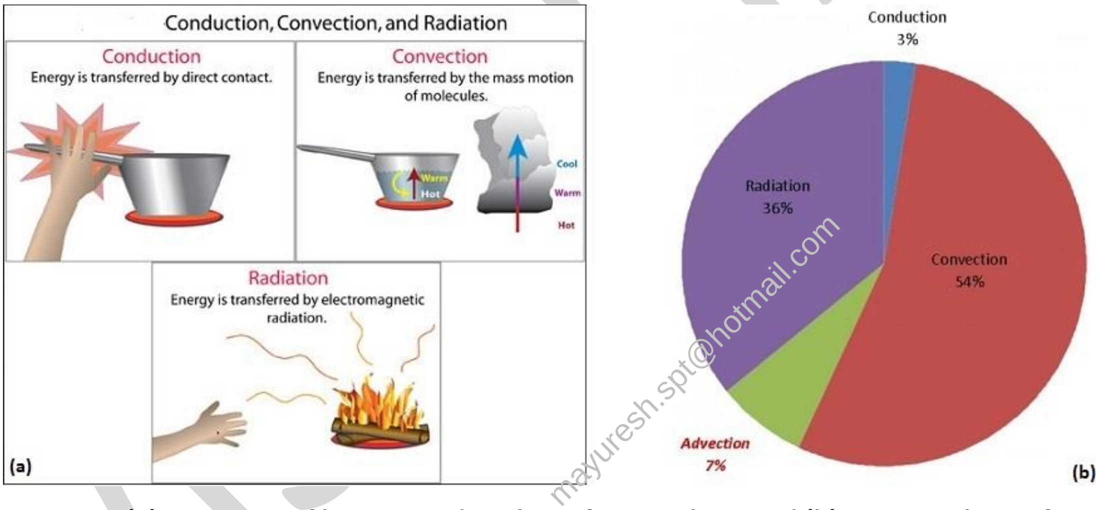

Figure 3 – (a) processes of heating and cooling of atmosphere and (b) per cent share of processes in heating up of atmosphere

4. **Advection:** The transfer of heat through horizontal movement of air is called advection. These winds take the characteristics of their source of origin with them. The temperature of a place will rise if it lies on the path of winds coming from warmer regions. The temperature will fall if the place lies on the path of the winds blowing from cold regions. Horizontal movement of the air is relatively more important than the vertical movement. In summer seasons, 'Loo' of north India is a hot wind and 'Sirocco' is also a hot wind carries heat of Sahara desert to Mediterranean regions. In middle latitudes, most of diurnal (day and night) variation in daily weather is caused by advection alone.

2. Heat Budget

The average temperature of the earth overall does not change in spite of continuous supply of sun rays. This is possible only when an equal amount of energy is sent back to space by the earth's system. In the way there is balance between incoming solar radiation and outgoing

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terrestrial radiations. This balance is known as the **heat budget of the earth**. Figure 4 depicts the heat budget of the planet earth. Consider that the insolation received at the top of the atmosphere is 100 per cent. While passing through the atmosphere some amount of energy is reflected, scattered and absorbed. Only the remaining part reaches the earth surface.

Roughly **35 units** are **reflected** back to space even before reaching the earth's surface. The details of this reflected radiation are as under:

- Reflected from the top of clouds - 27 units
- Reflected by ice-fields on earth - 02 units
- Reflected by the atmosphere - 06 units

Total - 35 units

The reflected amount of radiation is called the **albedo of the earth**. The above given radiation does neither heat the atmosphere nor the earth's surface.

The remaining **65 units** are **absorbed** as:

- Absorbed by the atmosphere - 14 units
- Absorbed by the earth - 51 units (Scattered + direct radiation)

Total - 65 units

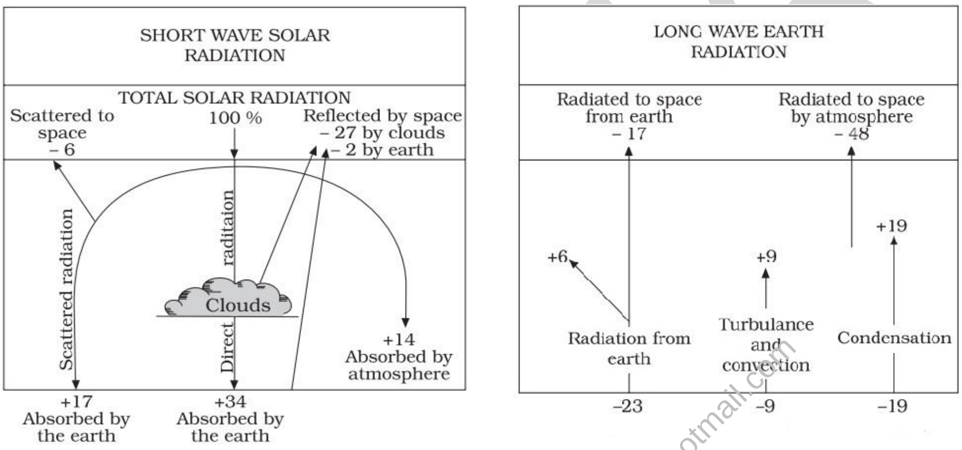

Figure 4 – Heat Budget of the Earth

Scattering takes place by gas molecules and dust particles. This takes place in all directions, some of it earthwards and some towards space. In overall, earth receives 51 units of radiation which in turn radiates back in the form of terrestrial radiation. The details of this reflected radiation are as under:

- Radiated to space directly - 17 units
- Radiated to atmosphere - 34 units

The details of 34 units radiation absorbed by atmosphere from terrestrial radiations are as under

- Absorbed directly - 06 units
- Absorbed through convection and turbulence - 09 units
- Absorbed through Latent heat of condensation[5] - 19 units

Total - 34 units

Total units absorbed by the atmosphere are 48 (14 units insolation + 34 units Terrestrial radiation). These are radiated back into space. Thus, the total radiation returning from the earth and the atmosphere respectively is:

- Radiated back by earth - 17 units
- Radiated back by atmosphere - 48 units

Total - 65 units

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These returning 65 units balance the total of 65 units received from the sun. This account of incoming and outgoing radiation always maintains the balance of heat on the surface of the earth. This is termed the heat budget or **heat balance** of the earth.

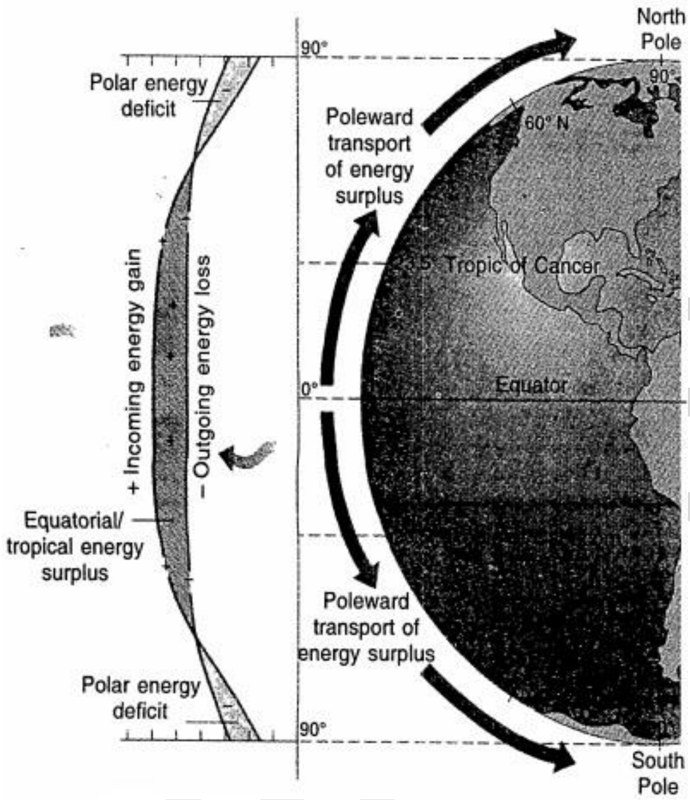


Figure 5 – heat energy budget by latitudes

2.1. Latitudinal Heat Balance

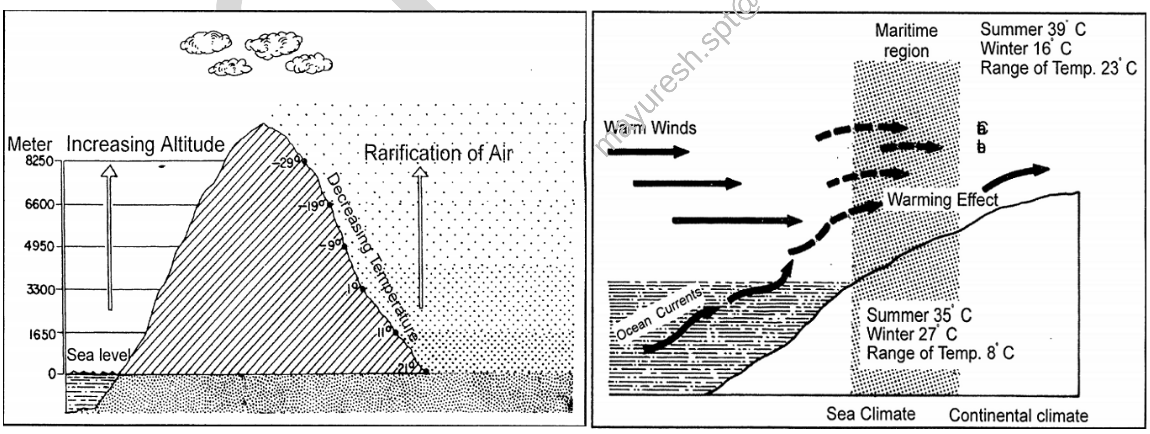
Although the earth as a whole maintains balance between incoming solar radiation and outgoing terrestrial radiation. But this is not true when we observe at different latitudes. Heat budget at latitudinal level is non-zero. As previously discussed, the amount of insolation received is directly related to latitudes. Some part of the earth has surplus radiation balance while the other part has deficit.

Figure 5 depicts the latitudinal variation in the net radiation balance of the earth — the atmosphere system. The figure shows that there is a surplus of net radiation balance between 40^0 N & S degrees and the regions near the poles have a deficit. This in theory should mean that tropical areas should get steadily warmers, and the Arctic and Antarctic even colder. But such is not the case. The surplus heat energy from the tropics is redistributed pole wards and as a result the tropics do not get progressively heated up due to the accumulation of excess heat or the high latitudes get permanently frozen due to excess deficit. This transfer of surplus heat from tropics to polar region is being performed by atmospheric and oceanic circulations such as winds and ocean currents. According to one estimate, about 75 per cent of heat transfer is carried out by atmospheric circulation and the remaining 25 per cent by the ocean currents. In fact, winds and ocean currents are produced due to imbalance of heat.

3. Temperature

The temperature is the measurement in degrees of how **hot (or cold) a thing (or a place) is**. The temperature of the atmosphere is not same across the Earth. It varies in spatial and temporal dimensions. The temperature of a place depends largely on the insolation received by that place. The interaction of insolation with the atmosphere and the earth's surface creates heat which is measured in terms of temperature. It is important to know about the temperature distribution over the surface of the earth to understand the weather, climate, vegetation zones, animal and human life etc. following factors determine the temperature of air at any place.

1. **The latitude of the place:** Intensity of insolation depends on the latitude. The amount of insolation depends on the inclination of sun rays, which is further depends upon the latitude of the place. At the equator sun's rays fall directly overhead throughout the year. Away from the equator towards poles, the inclination of the Sun's rays increases. In conclusion, if other things remain the same, the temperature of air goes on decreasing from the equator towards poles.
2. **The altitude of the place:** the atmosphere is largely heated indirectly by re-radiated terrestrial radiation from the earth's surface. Therefore, the **lower layers of the atmosphere are comparatively warmer than the upper layers, even in the same latitudes**. For example, Ambala (30 21' N) and Shimla (31 6') are almost at the same latitude. But the average temperature of Shimla is much lower than the Ambala. It is because Ambala is located in plain at an altitude of 272 m above sea level whereas Shimla is located at an altitude of 2202 m above sea level. In other words, the temperature generally decreases with increasing height (figure 6(a)). The rate of decrease of temperature with height is termed as the **normal lapse rate**. It is 6.5°C per 1,000 m. That's why, the mountains, even in the equatorial region, have snow covered peaks, like Mt. Kilimanjaro, Africa.
3. **Distance from the Sea:** the land surface is heated at a faster rate than the water surface. Thus the temperature of the air over land and water surfaces is not the same at a given time. In summers, the sea water is cooler than the land and in winters, land is much colder than the sea water. The coastal areas experience the sea breezes during the daytime and the land breezes during the night time. This has a moderating influence on the temperature of the coastal areas. Against this the places in the interior, far away from the sea, have extreme climate. The daily range of temperature is less near the coastal area and it increases with increase in distance from the sea coast (figure 6(b)). The low daily range of temperature is the characteristic of marine climate. That's why, the people of Mumbai have hardly any idea of extremes of temperature.



(a) – effect of altitude **(b) – maritime influence**

Figure 6 – effect of altitude & distance from sea on temperature

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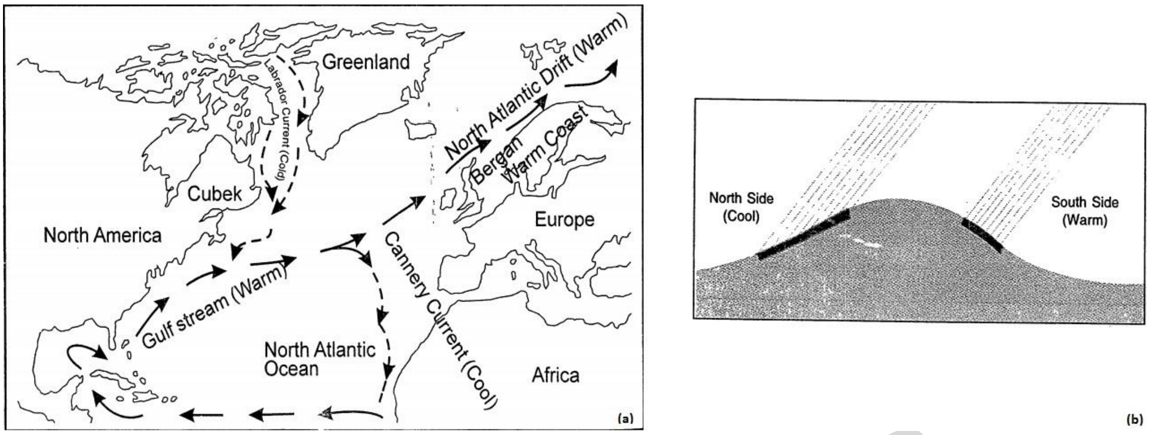


Figure 7 – (a) effect of ocean currents & (b) effect of slope on temperature

4. **Ocean Currents:** the effect of warm ocean currents and the cold ocean currents is limited to the adjoining coastal areas. The warm ocean currents flow along the eastern coast of tropical and sub-tropical regions and western coast of higher latitudes. On the other hand, cold ocean currents flow along the eastern coast of higher latitude and along the western coast of tropical and sub-tropical areas. The North Atlantic drift, an extension of Gulf Stream, warm the coastal districts of Western Europe (such as Norway) and British Isles keeping their ports ice-free (figure 7(a)).
5. **Air-mass circulation:** air masses in form of winds helps in the redistribution of temperature. The places, which come under the influence of warm air-masses experience higher temperature and the places that come under the influence of cold air masses experience low temperature. The effect of these winds is, however, limited to the period during which they blow. Local winds like cold Mistral of France considerably lower the temperature and Sirocco, a hot wind that blows from Sahara desert raises the temperature of Italy, Malta etc.

   The temperature rises at the time of arrival of temperate cyclones, while it falls sharply after their passage. Sometimes, local winds can cause sudden change in temperature. In northern India, 'Loo', a local hot wind, raise the temperature to such an extent that heat waves prolong for several days in continuation and many people die of sunstroke.
6. **Slope, Shelter and aspect:** slopes of a mountain facing the Sun experiences high temperature than the slopes on the leeward side due to more insolation (figure 7(b)). A steep slope experiences a more rapid change in temperature than a gentle one. Mountain ranges that have an east-west alignment like the Alps show a higher temperature on the south-facing 'sunny slope' than the north facing 'sheltered slope'. Consequently, there are more settlements in southern side and it is better utilized for agricultural and other purposes.

   The mountain ranges at certain places stop the cold winds and prevent the temperature from going down. This is found in areas where mountains lie in the direction facing the winds as in the case of Himalayas. **In the absence of Himalayas, winters of India would have been very different.**
7. **Nature of ground surface:** the nature of surface in terms of colour, vegetation, soil, land use, snow cover etc. affects the temperature of a place. In the tropical and subtropical deserts, the sandy surface record high temperature because they absorb most of the solar radiations. Snow has very high **albedo**[6] and thus, reflects much of the insolation without absorption. Thick vegetation (such as Amazon forest) cuts off much of the in-coming insolation and in many places sunlight never reaches the ground. It is cool in the jungle and its shade temperature is a few degrees lower than that of open spaces in corresponding

Student Notes:

latitudes. **Light soils reflect more heat than darker soils**. Dry soils like sands are very sensitive to temperature changes, whereas wet soils, like clay retain much moisture and warm up more slowly. Urban areas have relatively higher temperature than the surrounding.

3.1. Distribution of Temperature

The global distribution of temperature can well be understood by studying the **isotherms**. The Isotherms are lines joining places having equal temperature. As already discussed, latitudes have pronounced effect on the temperature, 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. Figure 8 and 9 show the distribution of surface air temperature in the month of January and July. In the northern hemisphere the land surface area is much larger than in the southern hemisphere. Hence, the effects of land mass and the ocean currents are well pronounced. Following are the chief features of isotherms:

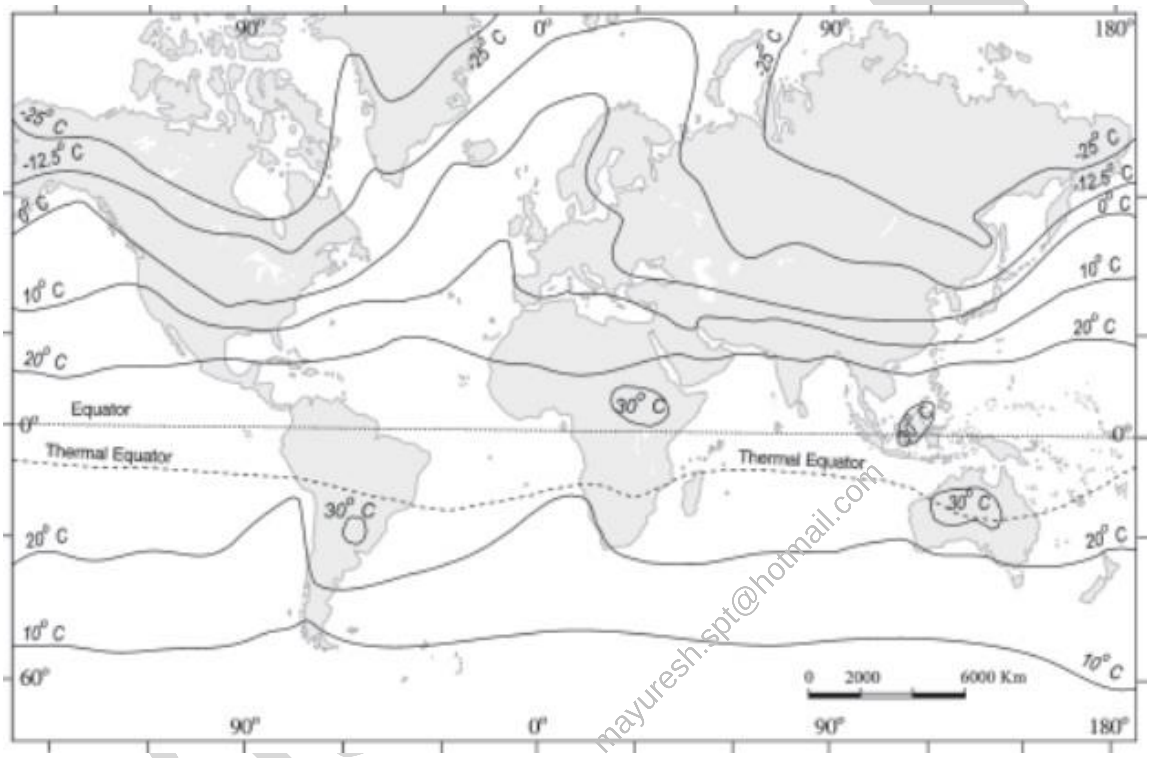


Figure 8 – isotherms in the month of January

- The isotherms are generally parallel to equator. They show successive temperature decrease towards the poles.
- The rate of change of temperature is indicated by the spacing between isotherms. Closely drawn isotherms indicate rapid change in temperature and vice-versa.
- The isotherms deviate to the north over the ocean and to the south over the continent in January. It is for two reasons – warm and cold ocean currents and difference between the temperature of land and water. For example, the presence of warm ocean currents, Gulf Stream and North Atlantic drift, make the Northern Atlantic Ocean warmer and the isotherms bend towards the north. Over the land the temperature decreases sharply and the isotherms bend towards south in Europe. The mean January temperature along 60° E longitude is minus 20° C both at 80° N and 50° N latitudes.
- In the southern hemisphere, the isotherms are more or less parallel to the latitudes due to less landmass and the variation in temperature is more gradual than in the northern

hemisphere. The isotherm of 20° C, 10° C, and 0° C runs parallel to 35° S, 45° S and 60° S latitudes respectively.

- In July the isotherms generally run parallel to the latitude.

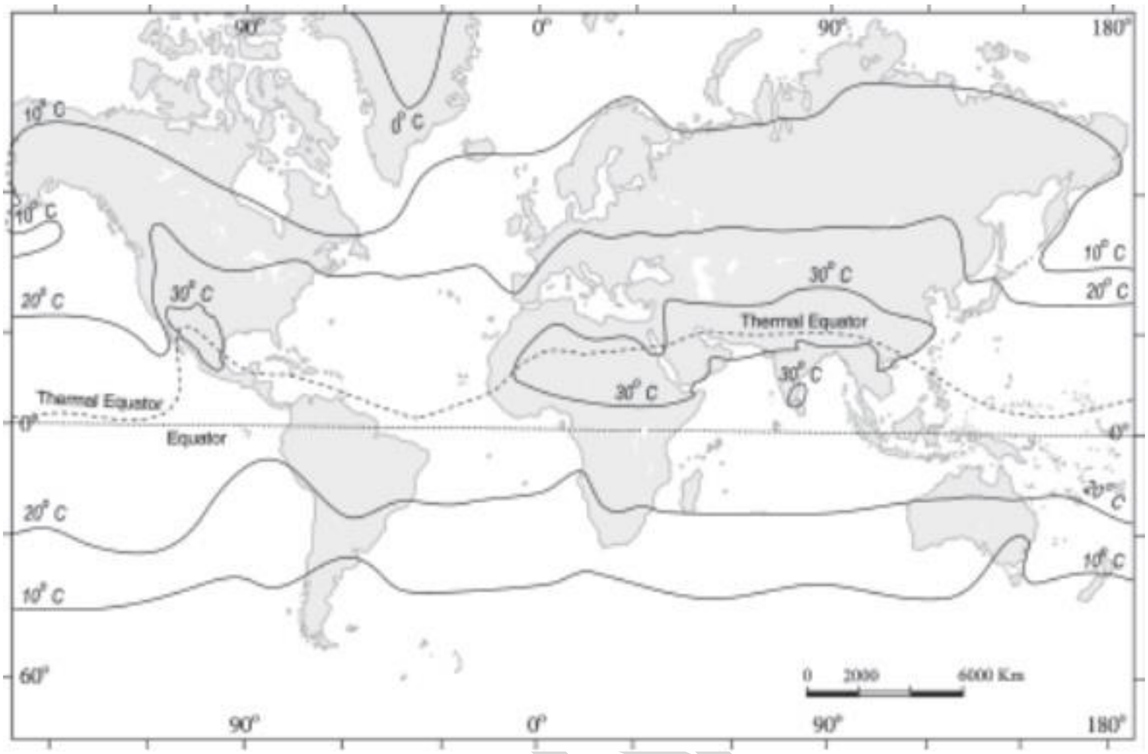


Figure 9 – isotherms in the month of July

3.2. Temperature Anomaly

The difference between the mean temperature of any place and the mean temperature of its parallels is known as temperature anomaly. On the map the lines joining the places of equal temperature anomaly are known as Isothermal anomaly lines.

Temperature anomaly could be positive or negative. Due to uneven distribution of land and water the maximum temperature anomalies are found in the Northern Hemisphere and minimum in the Southern Hemisphere.

3.3. Temperature Inversion

As already discussed, temperature decreases with increase in altitude. In normal conditions, as we go up, temperature decreases with normal lapse rate. It is 6.5°C per 1,000 m. Against this normal rule sometimes, instead of decreasing, temperature may rise with the height gained. The cooler air is nearer the earth and the warmer air is aloft. This rise of temperature with height is known as **Temperature inversion**. Temperature inversion takes place under certain specific conditions. These are discussed below:

- **Long winter nights:** if in winters the sky is clear during long nights, the terrestrial radiation is accelerated. The reason is that the land surface gets cooled fairly quickly. The bottom layer of atmosphere in contact with the ground is also cooled and the upper layer remains relatively warm.
- **Cloudless clear sky:** The clouds obstruct the terrestrial radiation. But this radiation does not face any obstacles for being reflected into space when the sky is clear. Therefore the ground is cooled quickly and so is the air in contact with it cooled.

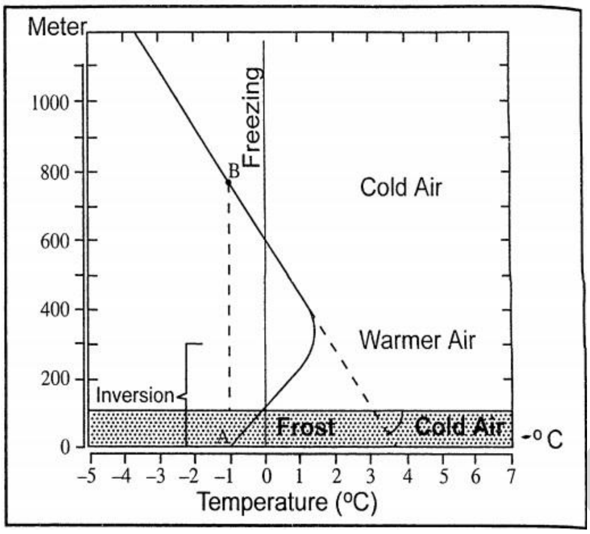


Figure 10 – temperature inversion

- **Dry air:** humid air absorbs the terrestrial radiation but dry air is no obstruction to terrestrial radiation and allows the radiation to escape into space.
- **Calm atmosphere:** the blowing of winds bring warm and cold air into contact. Under conditions of calm atmosphere the cold air stays put near the ground.
- **Ice covered surface:** in ice covered areas due to high albedo less insolation is received. During night due to terrestrial radiation most of the heat is lost to atmosphere and the surface is cooled. The air in contact with it is also cooled but the upper layer remains warm.

The stability of the night time **temperature inversion is usually destroyed soon after sunrise** as the sun's energy warms the ground, which warms the air in the inversion layer. The warmer, less dense air then rises, destroying the stability that characterizes the nightly inversion. **The phenomenon of inversion of temperature is especially observed in valleys**. During winters the mountain slopes cool very rapidly due to the quick radiation of heat. The air resting above them also becomes cold and its density increases. Hence, it moves down the slopes and settles down in the valleys. This air pushes the comparatively warmer air of valleys upwards and leads to the phenomenon of inversion of temperature. That is why, apple orchids in Himalayan region, tea garden of Darjeeling are found in upper slopes of the valleys.

<u>Effect on Humans</u>

- In cities, impurities present in the atmosphere such as smoke, dust particles and other pollutants do not go up in the air due to temperature inversion. They form dense fog near the earth's surface, especially in winters. It causes problems in breathing. Frost formed may be harmful for crops in fields.
- At some places, people lit fire or use big blowers to mix hot and cold air in order to drain off the area of the adverse conditions created by temperature inversion.
- In valleys people make terraced fields in the upper slopes and also settle down there.

3.4. Temperature Ranges

Temperature of a place varies within a day and also differs in different seasons. Range of temperature is the difference between maximum and minimum temperatures. There are two terms which are used to consider temperature ranges.

1. **Diurnal range of temperature:** the daily pattern of temperature change that we normally experience illustrates energy changes on a small time scale. On a calm day with little cloud, air temperatures usually reach their **minimum just before sunrise**, because the ground has

been giving off long-wave radiation all through the night, gradually becoming colder and cooling the air above by conduction. With sunrise, temperature of the ground begins to rise. Maximum insolation receives at midday. But the **peak of air temperature is usually about 2:00 PM**. After sun-set, the air initially remains fairly warm as it is still being heated by long-wave radiation from the ground, but this gradually expires. Desert areas typically have the greatest diurnal temperature variations while Low lying, humid areas typically have the least range.

2. **Annual average range of temperature:** it is the monthly range of temperature or the **difference between the average temperature of hottest month and average temperature of the coldest month** of the year. The annual range is lower in low latitudes and higher in high latitudes. In the same latitudes, it is higher over the continents and lower over the oceans and coastal regions. The highest annual range of temperature is more than 60° C over the north-eastern part of Eurasian continent. This is due to continentality. The least range of temperature, 3°C, is found between 20° S and 15° N.

4. Atmospheric Circulation

Varying amount of insolation received by the earth causes differential heating of the earth and its atmosphere. Temperature difference thus produced account for the density differences in the air. Air expands when heated and gets compressed when cooled. This results in variations in the atmospheric pressure. The result is that it causes the movement of air from high pressure to low pressure, setting the air in three-dimensional motion on global scale. Air in horizontal motion is wind. Atmospheric pressure also determines when the air will rise or sink. The wind redistributes the heat and moisture across the planet, thereby, maintaining a constant temperature for the planet as a whole. The vertical rising of moist air cools it down to form the clouds and bring precipitation. There is, in fact, an intimate relationship between winds and pressure, and knowledge of pressure variations is a prerequisite to understanding air motion.

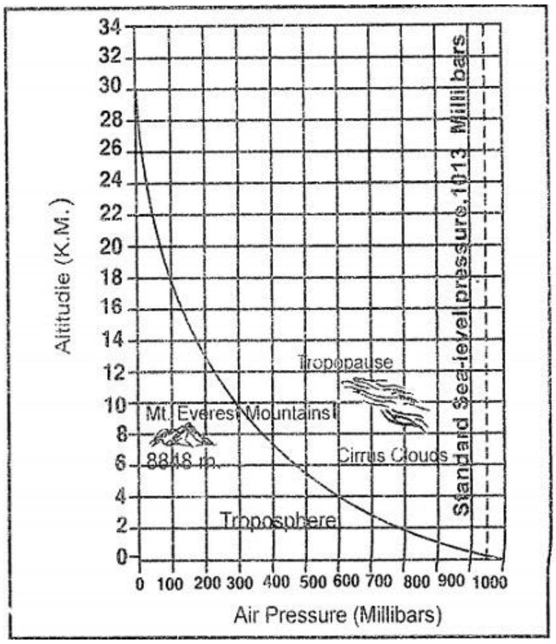
4.1. Atmospheric Pressure

The atmosphere is held on the earth by the gravitational pull of the earth. A column of air exerts weight in terms of pressure on the surface of the earth. 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**. Pressure is normally measured in millibars or pascals and spatial variations of pressure are depicted on maps by means of **isobars**, which are lines connecting places having the same barometric pressure. The actual pressure at a given place and at a given time fluctuates and it generally ranges between 950 and 1050 millibars. Air pressure is measured with the help of a mercury **barometer** or the aneroid barometer.

The gradual change of pressure between different areas is known as the barometric slope or pressure gradient. The closer the isobars are together, the greater the pressure gradient; for example, widely spaced isobars indicate a weak pressure gradient.

4.2. Pressure Variations

In the lower atmosphere the pressure decreases rapidly with height with decrease in density of air. It does not always decrease at the same rate. But to make calculations simple, a decrease of about 1 mb for each 10 m increase in elevation is taken into consideration (figure 11). In spite of high vertical pressure gradient, we do not experience strong vertical air currents. This is possible because of equal and opposite gravitation force acting upon air.



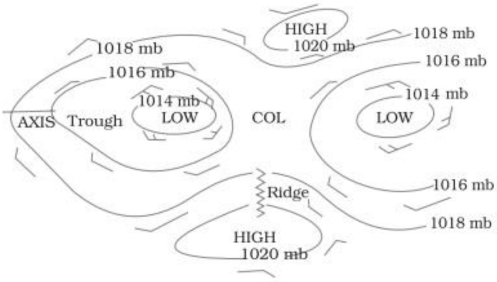


Figure 11 - vertical pressure variation **Figure 12 - Isobars, High pressure and Low pressure system**

The effects of low pressure are more clearly experienced by the people living in the hilly areas as compared to those who live in plains. In high mountainous areas rice takes more time to cook because low pressure reduces the boiling point of water. Breathing problem such as faintness and nose bleedings are also faced by many trekkers from outside in such areas because of low pressure conditions in which the air is thin and it has low amount of oxygen content.

Unlike vertical high pressure gradient, small horizontal pressure gradients are highly significant in terms of the wind direction and velocity. In order to eliminate the effect of altitude on pressure, it is measured at any station after being reduced to sea level for purposes of comparison. Figure 12 shows the patterns of isobars corresponding to pressure systems. Low pressure system is enclosed by one or more isobars with the lowest pressure in the centre. High-pressure system is also enclosed by one or more isobars with the highest pressure in the centre. The terms '**high pressure**' and '**low pressure**' do not usually signify any particular absolute values, but are used relatively.

Sea-level pressure conditions over the globe for both January (figure 13) and July (figure 14) show some marked differences between the two hemispheres. The northern hemisphere tends to have the greater seasonal contrasts in its pressure distributions and the southern hemisphere exhibits much simpler average pressure patterns overall. These differences are largely related to the unequal distribution of land and sea between the two hemispheres. Ocean areas, which dominate the southern hemisphere, tend to be much more equable than continents in both temperature and pressure variations.

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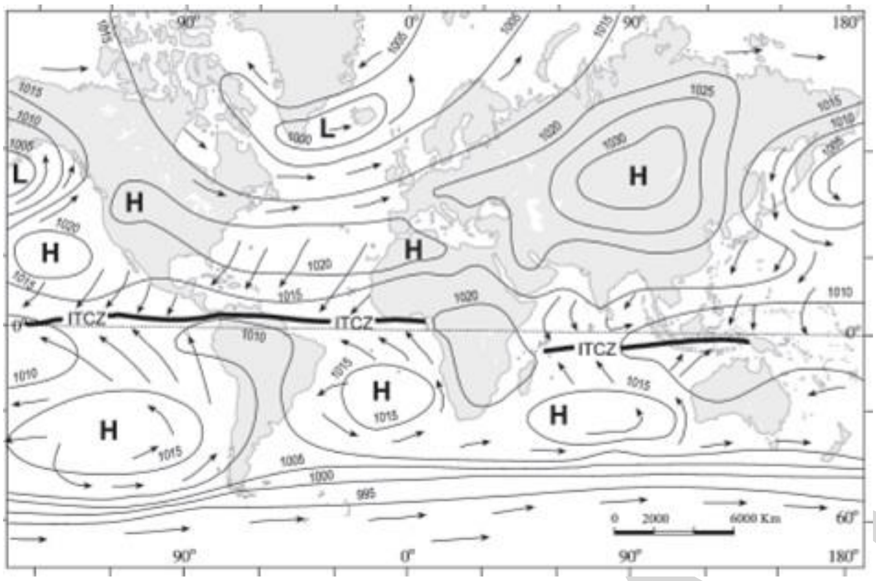


Figure 13 – Distribution of pressure (in mb) for January month

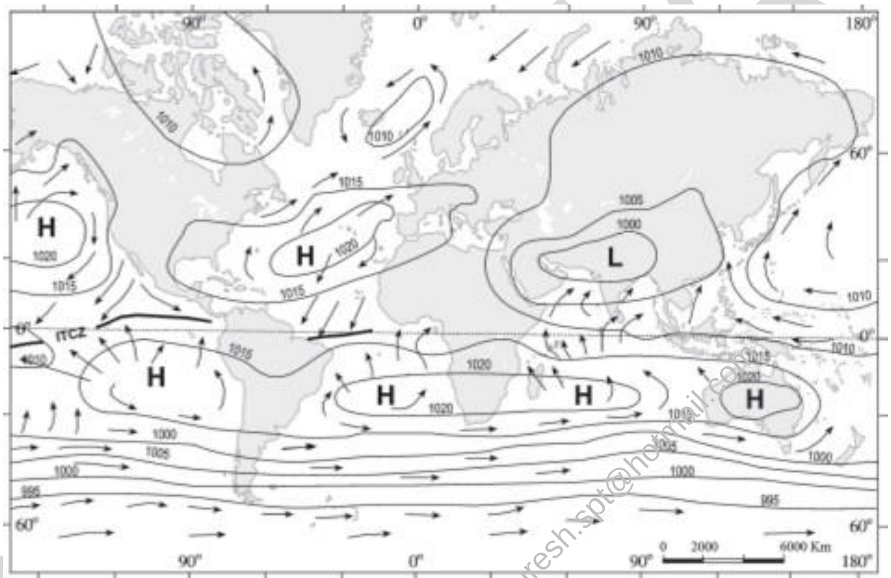


Figure 14 – Distribution of pressure (in mb) for July month

4.3. Forces Governing Air Movement

We know that the air pressure is unevenly distributed in the atmosphere and air attempts to balance this unevenness. Hence, it moves from high pressure areas to low pressure areas. Horizontal movement of air in response to difference in pressure is termed as **wind** while vertical or nearly vertical moving air is called **air current**. Both winds and air currents form the system of circulation in the atmosphere.

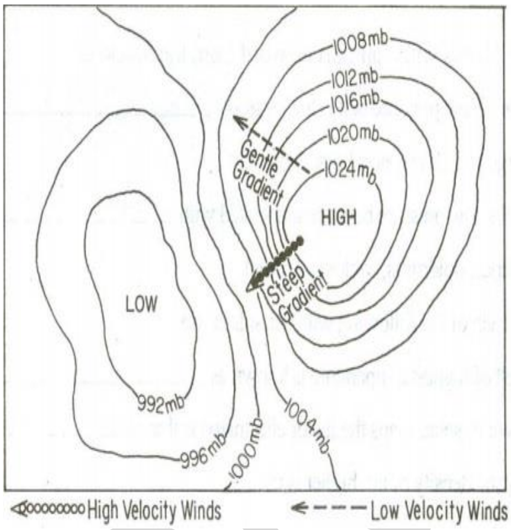
4.3.1. Pressure Gradient

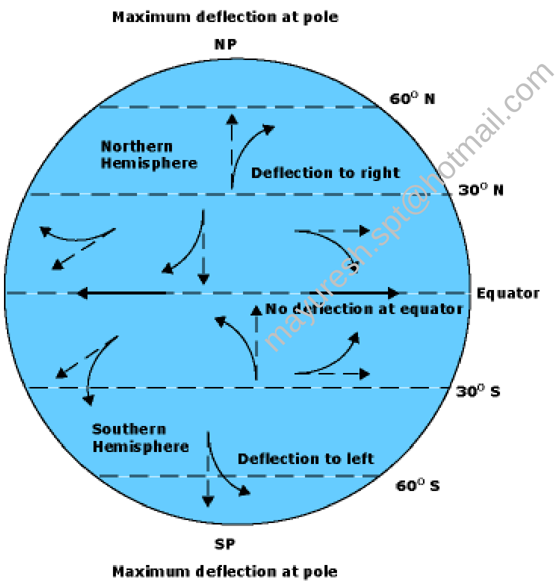
The existence of pressure differentials in the atmosphere is the immediate primary force causing air movement. The rate of change of pressure with respect to distance is the **pressure gradient**. The pressure gradient force always acts down the pressure gradient, attempting to cause the general movement of air away from high-pressure towards low pressure areas. The force exerted is proportional to the steepness of the gradient (figure 15(a)). The gentler the pressure gradient slower is the speed of the wind and vice-versa.

If alone this force is exerted to the air, wind would have direction perpendicular to the isobars. However, there are other forces also which, in fact, make wind to flow more nearly parallel to the isobars.

4.3.2. Coriolis Force

Winds do not cross the isobars at right angles as the pressure gradient directs them. They get deflected from their original paths. One of the most potent influences on wind direction is the deflection caused by the earth's rotation on its axis. This deflection is always to the right of the direction of motion in the northern hemisphere and to the left in the southern hemisphere (figure 15(b)). This influence is known as **Coriolis force**.





(a) Relationship between pressure **(b) Coriolis force under action gradient and speed of winds**

Figure 15 – forces governing air movement

The degree of the deflecting force varies with the speed of the moving air and with latitude. The faster the wind, the greater the effect of rotation can be. Similarly, the rate of deflection increases with the increasing distance from the Equator because the Coriolis force is zero at the Equator and maximum at Poles. It must be noted that it is an apparent or relative deflection. If viewed from outer space, objects moving across the face of the earth would not in fact appear to be deflected. In relation to star positions, they would travel in a straight line, while the earth rotates beneath them. The phenomenon affects all freely moving objects – air, ocean currents, rockets and projectiles etc. Thus, it is not actually any force. But it is simplest to accept that deflection is caused by a force.

4.3.3. Centripetal Force

This force applies when the isobars are curved, as within cyclones. The fact that air is following a curved path means that in addition to the pressure gradient and the Coriolis force, a third force is acting centripetally, pulling air inwards. Wind which is in balance with these three forces is known as the **gradient wind**.

4.3.4. Frictional Force

It lessens the speed of the wind. It is greatest at the surface and its influence generally extends upto an elevation of 1 - 3 km. Over the sea surface the friction is minimal. By reducing speed of wind, it weakens the Coriolis force. This allows the pressure gradient to assert its greater strength by causing the air to flow more towards low pressure. Thus, the usual situation is that surface winds flow at a slight angle to the isobars (figure 16(b)).

4.4. Geostrophic Wind

The velocity and direction of the wind are the net result of the wind generating forces. The winds in the upper atmosphere, 2 - 3 km above the surface, are free from frictional effect of the surface and are controlled by the pressure gradient and the Coriolis force. At such height in the free atmosphere, winds generally blow at right angles to the pressure gradient: this indicate that the pressure gradient force is exactly balanced by the Coriolis force acting in a diametrically opposite direction. This sort of air motion is known as the **geostrophic wind** (figure 16(a)).

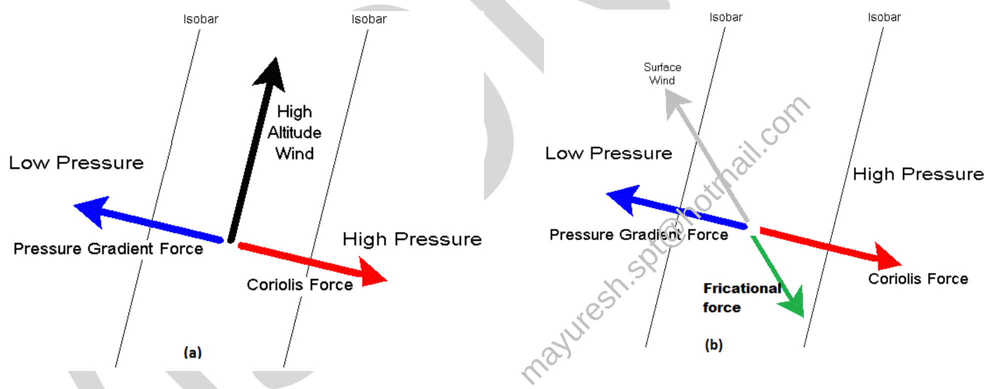


Figure 16 – forces governing air movement: (a) geostrophic balance between pressure gradient and Coriolis force; (b) the additional effect of frictional force on surface wind

Not all winds are exactly geostrophic. As pressure pattern change, the balance is upset, but the wind always strives to readjust itself until it obtains the new geostrophic speed.

4.5. Distribution of Pressure Belts

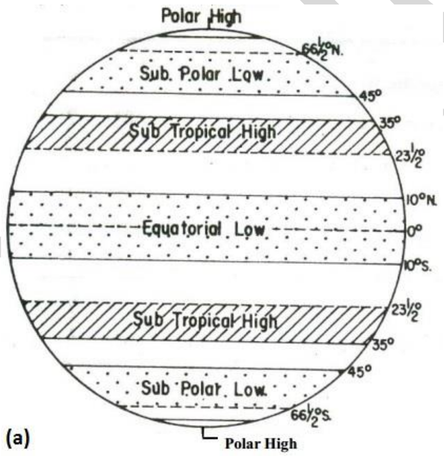
The horizontal distribution of air pressure across the latitudes is characterized by high or low pressure belts (figure 17(a)). These pressure belts are:

- **Equatorial low pressure belt:** This belt extends from equator to 10^0N and 10^0S latitudes. This belt is **thermally produced** due to heating by Sun.. Due to excessive heating horizontal movement of air is absent here and only vertical currents are experienced in this belt. Therefore, this belt is called **doldrums** (the zone of calm). . This belt is also known as-**Inter Tropical Convergence Zone (ITCZ)** because the trade winds flowing from sub tropical high pressure belts converge here.

- **Sub-tropical high pressure belt:** these extend roughly between 25^0 and 35^0 latitudes in both the Hemispheres. The existence of these pressure belts is due to the fact that the up rising air of the equatorial region is deflected towards poles due to the earth's rotation. After becoming cold and heavy, it descends in these regions and get piled up. This results in high pressure. Calm conditions with feeble and variable winds are found here.. In southern hemisphere, this belt is broken by small low-pressure areas in summer over Australia and South Africa. In northern hemisphere, the belt is more discontinuous by the presence of land masses, and high pressure occurs only over the ocean areas as discrete cells; these are termed the **Azores** and **Hawaiian cells** in the Atlantic and Pacific areas respectively.

  These belts are also called **Horse latitudes**. In older days, vessels with cargo of horses passing through these belts found difficult in sailing under these calm conditions. They used to throw the horses in the sea in order to make the vessels lighter. In the upper atmosphere over this belt the upper level westerlies and anti-trade winds converge and set up descending currents in the atmosphere.

- **Sub-polar low pressure belt:** it extends along 60^0 latitudes (55^0-65^0) in both the hemisphere. These belts are not thermally induced instead the winds coming from the sub-tropics and the polar regions converge in this belt and rise upward. The great temperature contrast between the subtropical and the polar regions, gives rise to cyclonic storms in this belt. In Southern hemisphere, this low pressure belt is more pronounced due to vast presence of ocean and also referred as the **sub-antarctic low**. But in the northern hemisphere, there are large land masses along 60^0 latitudes which are very cold. Therefore, the pressures over these landmasses are increased. Thus, the continuity of the belt is broken.
- **Polar high pressure belt:** Because of low temperature, air compresses and its density increases. Hence, high pressure is found here throughout the year. This is more marked over the land area of the Antarctic continent than over the ocean of the North Pole. In northern hemisphere, high pressure is not centered at the pole, but it extends from Greenland to Islands situated in the northern part of Canada.



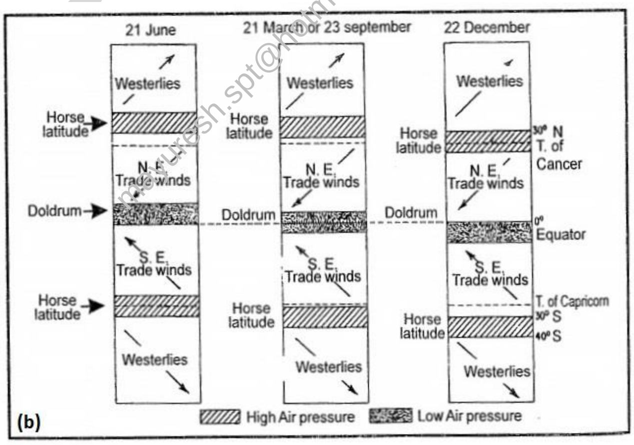


Figure 17 – (a) global pressure belts and (b) shifting of pressure belts

4.6. Shifting of Belts

Pressure belts are not fixed. The main cause of their formation is the uneven distribution of temperature on the surface of earth. Consequently, the pressure belts swing either to the north (in July) or the south (in December) of the equator by following the apparent annual migration of the sun (figure 17(b)). Sun's movement is recorded between tropic of Cancer and tropic of Capricorn. During the month of July, low pressure equatorial belt extends upto the tropic of

Cancer in Asian region. While in January, it extends to latitudes 10^0-15^0 S. Most profound effect of shifting of belts is seen in the temperate region. Winds blowing from the Horse latitudes in the form of westerlies create unique climatic conditions in the temperate parts of the world, especially in the Mediterranean region.

4.7. General Circulation of the Atmosphere

As discussed earlier that wind is the result of pressure gradient which is largely caused by differential heating of the earth. Winds in the atmosphere are neither unidirectional nor have a same pattern as we go up in the atmosphere. In fact, winds may change their direction and intensity multiple times within same day. Largely, wind movement in the atmosphere may be classified into three broad categories:

- **Primary circulation:** it includes planetary wind systems which are related to the general arrangement of pressure belts on the earth's surface. The pattern of the movement of the planetary winds is called the **general circulation of the atmosphere**. In fact, it is the primary circulation patterns which prepare the broad framework for the other circulation patterns.
- **Secondary circulation:** it consists of cyclones and anti-cyclones, monsoon
- **Tertiary circulation:** it includes all the local winds which are produced by local causes such as topographical features, sea influences etc. Their impact is visible only in a particular area.

4.7.1. Planetary Winds

Primary or planetary winds blow from high pressure belts to low pressure belts in the same direction throughout the year. They blow over vast area of continents and oceans. Trade winds, Westerlies and polar easterlies together form the planetary wind circulation (figure 18). These are described below:

- The air at the **Inter Tropical Convergence Zone (ITCZ)** rises because of convection caused by high insolation and a low pressure is created. The winds from the tropics converge at this low pressure zone. The converged air rises along up. It reaches the top of the troposphere up to an altitude of 14 km. and moves towards the poles. This causes accumulation of air at about 30^0 N and S. Part of the accumulated air sinks to the ground and forms a subtropical high. Another reason for sinking is the cooling of air when it reaches 30^0 N and S latitudes. Down below near the land surface the air flows towards the equator as the **easterlies[1] or tropical easterlies or trade winds**. Because of Coriolis force, their direction becomes north-east and south-east in northern and southern hemisphere respectively. The easterlies from either side of the equator converge in the Inter Tropical Convergence Zone (ITCZ). Thus, winds originated at ITCZ come back in a circular fashion. Such a cell in the tropics is called **Hadley Cell**.
- In the middle latitudes (30^0-60^0) the circulation is that of sinking cold air that comes from the poles and the rising warm air that blows from the subtropical high pressure belt. These winds are deflected due to coriolis force and become **westerly** in both the hemisphere. Deflected wind is called **westerlies**. These winds meet along the sub-polar low pressure belt to raise high in the troposphere. From here, air moves away in both directions – towards pole and equator. These winds start descending down above the sup-tropical high pressure belt and polar high pressure belt to form cells. These cells are called **Ferrel cell** and **Polar cell** respectively.

[1] Wind direction is reported by the direction from which it originates. For example, a easterly wind blows from the east to the west.

Student Notes:

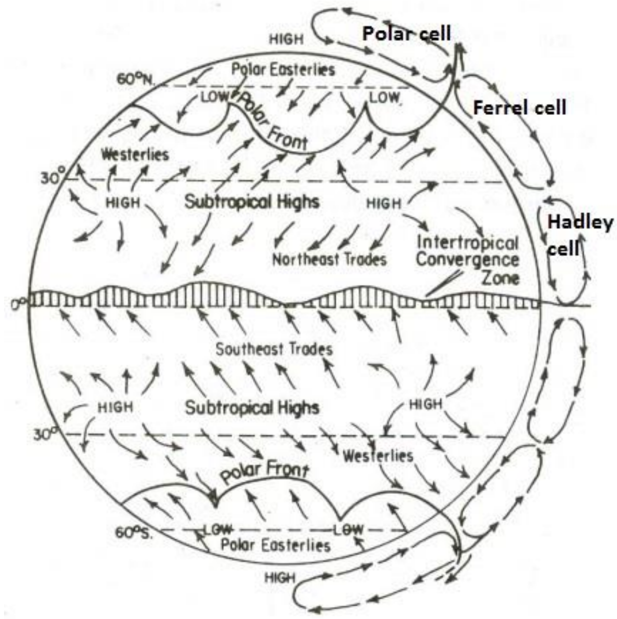


Figure 18 – Planetary winds

- The prevailing westerlies are relatively more variable than the trade winds both in direction and intensity. There are more frequent invasions of polar air masses along with the travelling cyclones and anti-cyclones. These moving cells of low and high pressures largely affect the movement of westerlies. The westerlies are stronger in the cold. In the southern hemisphere, westerlies are so powerful and persistent due to absence of land between 40^0-60^0 S that these are called '**roaring forties**', '**furious fifties'** and '**screaming sixties'** along 40^0 S, 50^0 S and 60^0 S latitudes.
- Winds move away from polar high pressure to sub-polar low pressure along the surface of the earth in Polar cell. Their direction becomes easterlies due to coriolis force. These are called **polar easterlies**.
- Winds coming from the sub-tropical and the polar high belts converge to produce cyclonic storms or low pressure conditions. This zone of convergence is also known as **polar front (see fronts and cyclones)**.

4.8. Local Winds

Besides major wind systems of the earth's surface, there are certain types of winds which are produced by purely local factors and therefore, are called **local winds**. These local winds play a significant role in the weather and climate of a particular locality. Following is a brief account of some of the well-known local winds which are found in different parts of the world.

4.8.1. The Land and Sea Breezes

These winds are defined as the complete cycle of diurnal local winds occurring on sea coasts due to differences in the surface temperature of sea and adjacent land (figure 19). There is complete reversal of wind direction of these coastal winds. The land and sea breeze system is very shallow with average depth of 1-2km. Over lakes, the height of circulation is much less. Warm tropical areas, where intense solar heating persists throughout the year, experience stronger and regular breezes compare to higher latitudes. Details of land and sea breezes are given in table 2.

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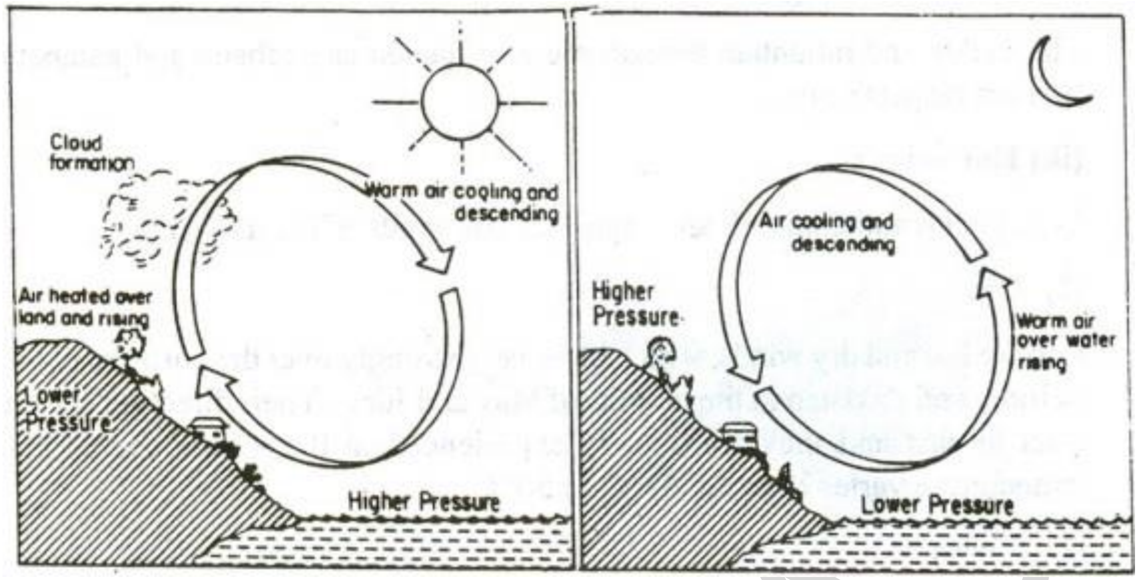

Figure 19 – Sea and Land Breezes

Sea Breeze	Land Breeze
During the day the land heats up faster and becomes warmer than the sea. The heated air rises giving rise to a low pressure area, whereas the sea is relatively cool and the pressure over sea is relatively high.	In the night, the land cools up faster than the surrounding sea. This creates relatively high pressure on land.
Pressure gradient is created from sea to land.	Pressure gradient is created from land to sea.
the wind blows from the sea to the land as the sea breeze	the wind blows from the land to the sea as the land breeze
Reaches at maximum intensity in mid-afternoon	Reaches at peak shortly before the sunrise
Helpful for fishermen in returning from sea after a good catch.	In morning, fishermen enter into sea with the help of land breeze and stays there till mid-afternoon.

Table 2 – land and sea breezes

4.8.2. The Mountain and Valley Breezes

Another combination of local winds that undergoes a daily reversal consists of the mountain and valley breezes (figure 20). During the day the slopes get heated up more than the valleys. Hence, the pressure is low over the slopes while it is comparatively high in the valleys below. Air moves up from slope and to fill the resulting gap the air from the valley blows up the valley. This wind is known as the **valley breeze or anabatic wind**. The valley breeze is sometimes accompanied by the formation of cumulus cloud near mountain peaks to cause orographic rainfall.

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 **mountain breeze or katabatic wind**.

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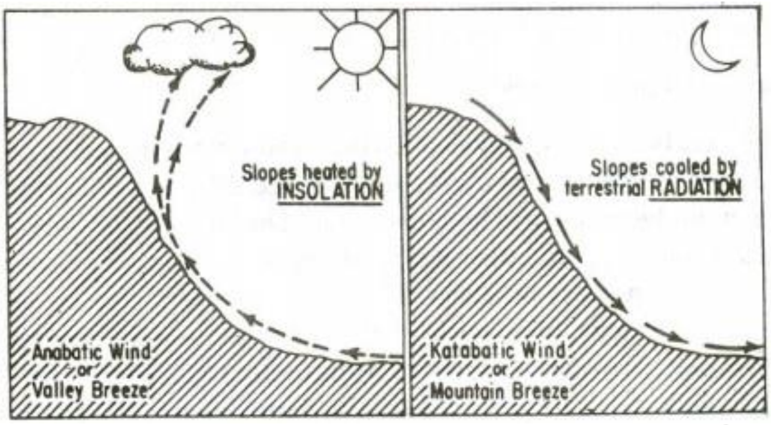


Figure 20 – mountain and valley breezes

4.8.3. Hot Local Winds

Local winds that are hot are caused by the advection of hot air from a warm source region. They may also be produced by dynamic heating of air as it descends from an elevated area to lowland. Few famous hot winds are:

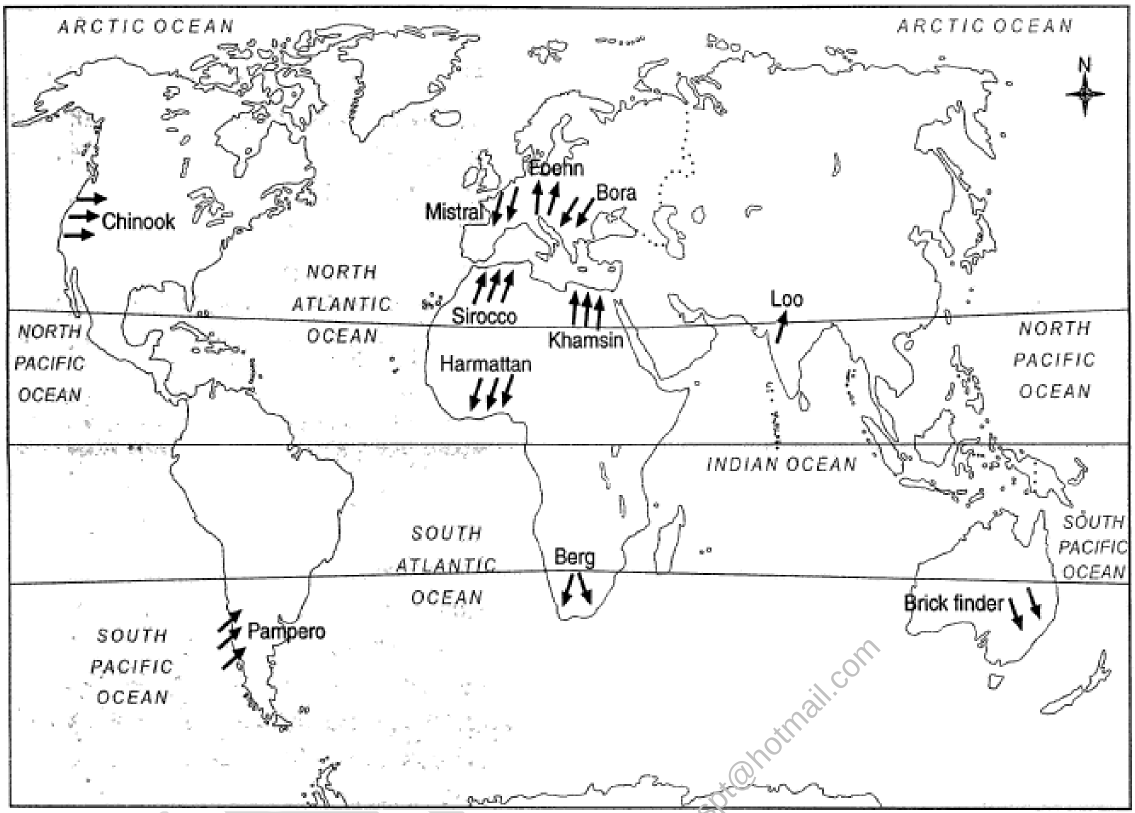
- '**Loo'** is a hot and dry wind, which blows very strongly over the **northern plains of India and Pakistan** in the months of May and June. Their direction is from west to east and they are usually experienced in the afternoons. Their temperature varies between 45°C to 50°C.
- '**Foehn'** is strong, dusty, dry and warm local wind which develops on the leeward side of the **Alps mountain ranges**. Regional pressure gradient forces the air to ascend and cross the barrier. Ascending air sometimes causes precipitation on the windward side of the mountains. After crossing the mountain crest, the Foehn winds starts descending on the leeward side or northern slopes of the mountain as warm and dry wind. The temperature of the winds varies from 15°C to 20°C which help in melting snow. Thus making pasture land ready for animal grazing and help the grapes to ripe early.
- '**Chinook'** is the name of hot and dry local wind, which moves down the eastern slopes of the **Rockies in U.S.A. and Canada**. The literal meaning of chinook is 'snow eater' as they help in melting the snow earlier. They keep the grasslands clear of snow. Hence, they are very helpful to ranchers.
- **'Sirocco'** is a hot, dry dusty wind, which originates in the Sahara desert. It is most frequent in spring and normally lasts for only a few days. After crossing the Mediterranean sea, the Sirocco is slightly cooled by the moisture from the sea. Still it is harmful for vegetation, crops in that region. Its other local names are **Leveche** in Spain, **Khamsin** in Egypt, **Gharbi** in Aegean Sea area.
- **Harmattan** is a strong dry wind that blows over northwest Africa from the northeast. Blowing directly from the Sahara desert, it is a hot, dry and dusty wind. It provides a welcome relief from the moist heat and is beneficial to health of people hence also known as 'the doctor'. It is full of fine desert dust which makes the atmosphere hazy and causes problems to the caravan traders. It may cause severe damage to the crops.

4.8.4. Cold Local Winds

There are certain local winds which originate in the snow-capped mountains during winter and move down the slopes towards the valleys. Few of important these are:

- **'Mistral'** originates on the Alps and move over France towards the Mediterranean Sea through the Rhone valley. They are very cold, dry and high velocity winds. They bring down temperature below freezing point in areas of their influence. As a protective measure, many of the houses and orchards of the Rhone valley have thick rows of trees and hedges planted to shield them from the Minstral.

- '**Bora'** is a cold, dry north-easterly wind blowing down from the mountains in the Adriatic Sea region. It is also caused by pressure difference between continental Europe and the Mediterranean Sea. This is usually occurs in winter. It sometimes attain speeds of over 150 kmph.
- **'Blizzard**' is a violent and extremely cold wind laden with dry snow. Such blizzards are of common occurrence in the Antarctic. Wind velocity sometimes reaches 160 kmph and temperature is as low as -7^{0}C.



4.9. Upper Air Circulation

It is now realized that the causes of weather on the ground are intricately bound up with what happens at higher levels in the atmosphere. This applies especially to the development of anti-cyclones and depressions and to the general circulation of winds around the globe. Such phenomena can only be appreciated by understanding air circulation in the upper layers. Broadly speaking, wind speed tend to increase with altitude because of lower air density, lower frictional force etc. Direction of wind also is not same. For instance, during the month of July, surface wind(monsoonal) blow from south-west direction in India while at the height of 10km there are swift winds blowing from east to west.

On a global scale, pressure patterns higher up tend to be much simpler than those at the surface level, largely because of the diminished thermal and mechanical effects of land masses. There is a falling pressure gradient from the sub-tropical areas towards the poles. The gradient is strongest in winter, when the temperature contrasts between the respective polar areas and the equator are most marked.

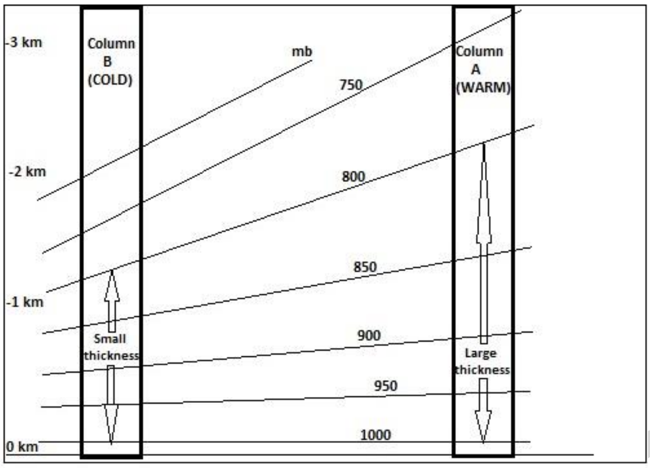


Figure 21 – different vertical temperature gradients in the two columns create an increasing pressure gradient.

4.9.1. Jet Streams

Changes in pressure distribution with height are largely related to changes of temperatures. We can see how this can be so with references to two adjacent columns of air in the troposphere depicted in figure 21. At ground level the pressure exerted by the two is the same, but important changes ensue if we assume that column A is warmer, and therefore less dense throughout than column B. This means that for any level higher up in the two columns, for instance at 2km, there is a greater pressure of air still above this level of column A than in column B. Therefore, a pressure gradient from A to B gradually develops and intensifies with height, where none existed at the surface. Now, it can be visualized that a gradual change of velocity of the wind with height, the wind at the top of the air layers being very much stronger than that lower down.

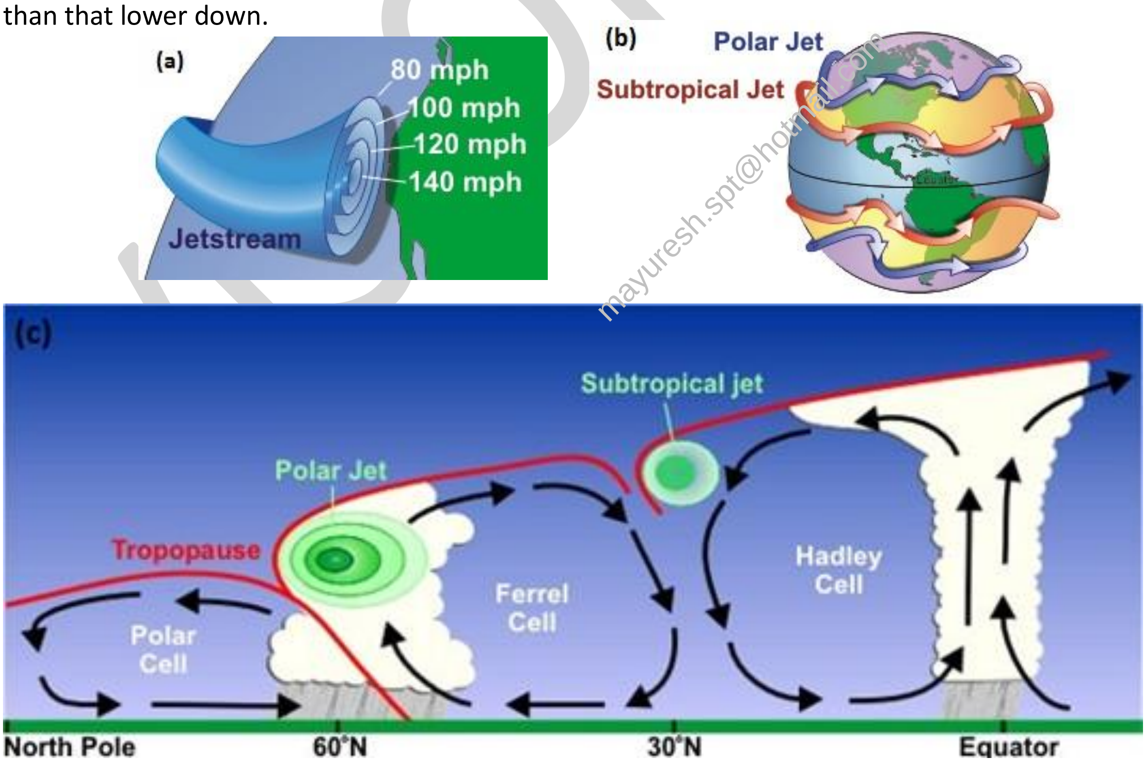


Figure 22 – jet streams: (a) maximum speed at centre; (b) Polar and subtropical jetstreams in both hemispheres; (c) cross-sectional view of jet streams

Applying this on a global scale by associating poles with cold air column and equator with warm air column, the gradual poleward decrease of temperature in the atmosphere from the equator should result in a large westerly component in the upper winds. It was found in 1940s during Second World War that high-flying aircraft encountered upper winds of very great velocity. These are known to be concentrated bands of rapid air movement, which are termed **jet streams**. Few of the features of jet streams are:

- These are narrow belts at the high altitude near the top of the troposphere.
- Their speed varies from about 110 km per hour (kmph) in the summer season to more than 180 kmph in the winter season.
- Their shape is circular. Speed in the jet streams decreases radially outwards (figure 22(a)). One way of visualizing this is to consider a river. The river's current is generally the strongest in the center with decreasing strength as one approaches the river's bank. It can be said that jet streams are "rivers of air".
- They are several hundred kilometers wide and about 2 km to 5km deep.
- The flow of jet streams is not in form of straight line. Their circulation path is wavy and meandering. These meandering winds are called **Rossby waves**
- They dip and rise in altitude/latitude, splitting at times and forming eddies, and even disappearing altogether to appear somewhere else.
- Jet streams also "follow the sun" in that as the sun's elevation increases each day in the spring, the average latitude of the jet stream shifts poleward. (By Summer in the Northern Hemisphere, it is typically found near the U.S. Canadian border.) As autumn approaches and the sun's elevation decreases, the jet stream's average latitude moves toward the equator.
- On occasions the jet stream breaks through the tropopause and enters into the lower stratosphere. Certain amount of water vapour manages to reach in lower stratosphere with jet streams and this layer exhibits occasional cirus clouds. At times, the jet stream effect extends down to an altitude of about 3 km from the earth's surface.
- There is a well marked longitudinal variation in the strength of the jet stream. In winter, the highest wind velocities of the jet stream are found near the east coast of Asia and weakest over the eastern Atlantic and Pacific Oceans. In summer, strongest jet is positioned along the Canadian border and Mediterranean region.

Two permanent jet stream zones occur in each hemisphere. One is sub-tropical jet stream and another is polar front jet stream. There is another jet stream which moves seasonally near equator. Description of these three streams is give below:

The polar front jet stream

- It is originated because of temperature difference.
- It is associated with the polar front zone[7] in each hemisphere (figure 23).
- It runs at a more meandering path than the Sub Tropical Jet Stream
- It extends between 40 and 60 latitudes in both Hemispheres.
- It is found at a height between 6km and 9km in the atmosphere.
- It swings towards poles in summers and towards equator in winter. When swinging to south it takes very cold air with it to subtropical region.

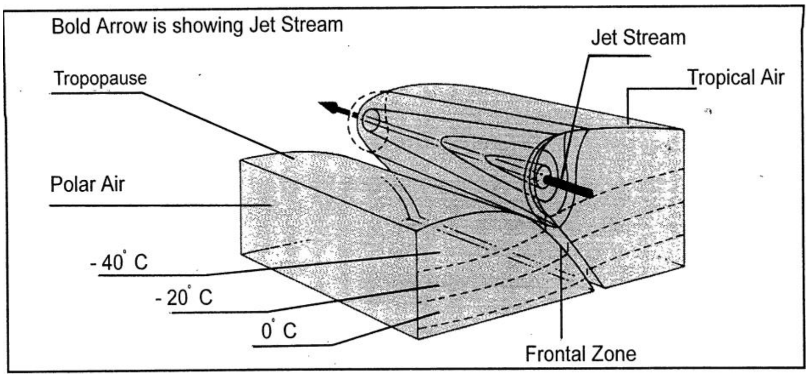


Figure 23 – origin of the Polar front Jet stream at polar front zone

Sub-tropical jet stream

- It runs between 25^0 and 30^0 latitudes in both the hemispheres.
- It blows constantly
- Its speed is comparatively lower than polar jet streams
- The air currents arising near about the equator descend at 30^0 N and S latitudes. A part of these air currents takes the form of Sub Tropical Jet streams.
- It swings to the north of Himalayas in summer in North India.

Eastern Tropical Jet Stream

- It is a seasonal Jet Stream.
- It blows between equator and 20^0N latitude at the time of South-West Monsoon in summer over south-east Asia, India and Africa.
- Its direction is opposite to that of other two jet streams. It runs in eastern direction.
- It is located comparatively at higher height between 14km and 16km
- Its speed is around 180 km per hour.

Consequence of Jet Stream

- They affect weather conditions
- They substantially contribute to originating cyclones, anticyclones, storms and depressions and influence their behaviour.
- The bursting of monsoon in India is said to be closely related to Eastern Tropical Jet streams.
- If the weather is not disturbed the aeroplanes running in their parallel directions gain great speed and considerably save fuel.
- Sometimes aeroplanes cannot be flown in opposite direction.
- These jet streams are still being investigated with respect to their effect on weather conditions.

5. Air Mass

When the air remains over a homogenous area for a sufficiently longer time, it acquires the characteristics of the area. Such homogenous areas have uniform characteristics in terms of temperature, pressure and moisture. The air with distinctive characteristics in terms of temperature and humidity is called an **air mass**. It is defined as a large body of air having little horizontal variation in temperature and moisture. The homogenous surfaces, over which air masses form, are called the **source regions**. There are five major source regions. These are:

1. Warm tropical and subtropical oceans
2. The subtropical hot deserts

Student Notes:

3. The relatively cold high latitude oceans
4. The very cold snow covered continents in high latitudes
5. Permanently ice covered continents in the Arctic and Antarctica

The air masses are classified according to the source regions. Air masses originated from tropical region are warm while those originated from polar region are cold. Air masses originated from these regions are called **primary air masses**. Accordingly, following types of airmasses are recognised:

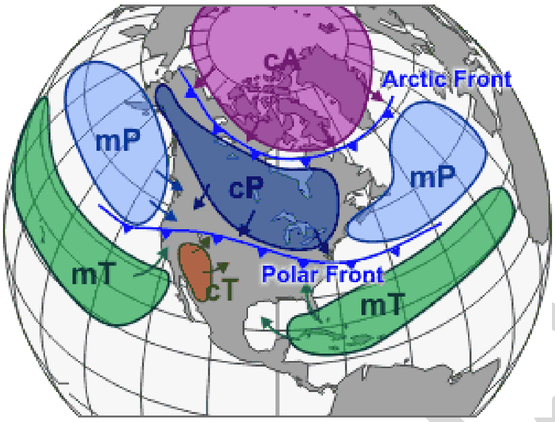


Figure 25 – Airmasses

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

Where 'm' stands for Maritime; 'c' stands for continental; 'T' stands for tropical; 'P' stands for polar and 'A' stands for arctic region.

As these air masses move around the earth they can begin to acquire additional attributes. For example, in winter an arctic air mass (very cold and dry air) can move over the ocean, picking up some warmth and moisture from the warmer ocean and becoming a maritime polar air mass (mP) - one that is still fairly cold but contains moisture. If that same polar air mass moves south from Canada into the southern U.S. it will pick up some of the warmth of the ground, but due to lack of moisture it remains very dry. Another way of changes is internal modification in the airmasses. The resultant air mass by these processes is termed as secondary air mass. Air masses can control the weather for a relatively long time period: from a period of days, to months. Most weather occurs along the periphery of these air masses at boundaries called fronts.

6. Fronts

When two different air masses with distinct properties (temperature, moisture, density, pressure etc.) meet, the boundary zone between them is called a **front**. These air masses are brought together by converging movements in the general atmospheric circulation. The process of formation of the fronts is known as **frontogenesis** while **Frontolysis** is the end stage of a front (table 3). The fronts do not mix readily. In fact, they come in contact with one another along sloping boundaries. These sloping boundaries are actually a transition zone across which a sharp contrast in weather condition occurs. The air masses are of vast size covering tens of thousands of square kilometers. Therefore, frontal zones of discontinuity about 15 to 200 kms wide are relatively narrow. So on the weather map they are represented by only a thick line. A front can be recognized with following observations:

Student Notes:

- Sharp temperature changes over a relatively short distance. Sometimes change of 10^0 to 20^0 C may be observed.
- Change in moisture content
- Rapid shifts in wind direction
- Pressure changes
- Clouds and precipitation patterns

Frontogenesis	Frontolysis
creation of altogether new fronts	destruction or dying of a front
Only after the process of frontogenesis have been in operation for quite some time, front do come into existence	Process of frontolysis must continue for some time in order to destroy an existing front.
is likely to occur when the wind blow in such a way that the isotherms become packed along the leading edge of the intruding air mass	likely to occur when fronts move into regions of divergent air flow on crossing the sub-tropical high pressure regions, the fronts generally disappear
Convergence of the wind toward a point or contraction towards a line augments the process of Frontogenesis.	divergence of the wind from a point is helpful to the process of frontolysis
Cyclonic wind shear witnesses the creation of fronts. Contrarily, the areas of anti-cyclonic wind shear do not allow the formation of fronts. Even the pre-existing fronts degenerate in such areas.	

Table 3 – difference between frontogenesis and frontolysis

As a result of the observations of atmospheric conditions at the surface and aloft, the following types of fronts are identified:

6.1. Warm Front

When a warmer and lighter air mass moves against an existing cold and dense airmass, it rises over the coldet and denser air mass. This type of front is known as warm front. (figure 26a). As the warm air gradually ascends the gently sloping surface of the wedge of cold air lying ahead, it cools. This cooling leads to the cloudy condensation and precipitation. Unlike the cold front, the changes in temperature and wind direction are gradual.

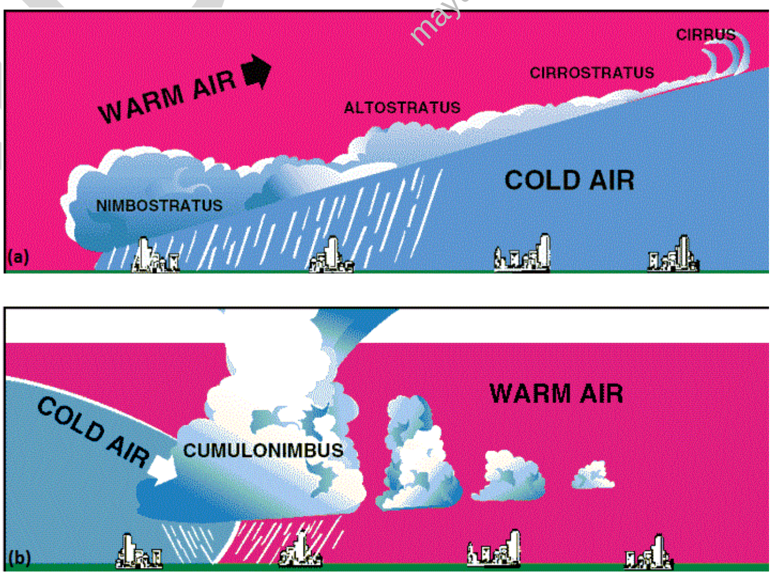


Figure 26 – Fronts: (a) Warm front; (b) Cold front

Student Notes:

6.2. Cold Front

When a cold and dense airmass forces its way under warm and lighter airmass it makes the warm and lighter airmass to ride over it. This type of front is called cold front. The effect of friction retards the air motion near the ground, while the free air aloft has a higher velocity. This causes the cold front to become much steeper than the warm front.

6.3. Stationary Front

A stationary front forms when a cold front or warm front stops moving. This happens when two masses of air are pushing against each other but neither is powerful enough to move the other. Winds blowing parallel to the front instead of perpendicular can help it stay in place.

6.4. Occluded Front

Sometimes a cold front follows right behind a warm front. A warm air mass pushes into a colder air mass (the warm front) and then another cold air mass pushes into the warm air mass (the cold front). Because cold fronts move faster, the cold front is likely to overtake the warm front. This is known as an occluded front.

At an occluded front, the cold air mass from the cold front meets the cool air that was ahead of the warm front. The warm air rises as these air masses come together. Occluded fronts usually form around areas of low atmospheric pressure. The fronts occur in middle latitudes and are characterised by steep gradient in temperature and pressure. They bring abrupt changes in temperature and cause the air to rise to form clouds and cause precipitation

There are two types of occlusion namely, cold front occlusion and war front occlusion (figure 27). The differences are given below in table 6.

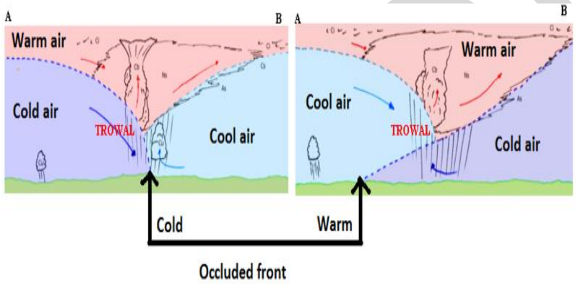


Figure 27- cold front occlusion and warm front occlusion

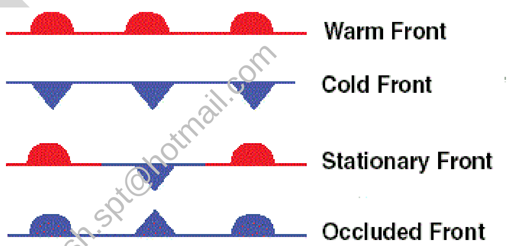


Figure 28 – symbols used for Fronts

Cold front occlusion	Warm front occlusion
Occurs when the cold air which overtakes the warm air is colder than the retreating cold air	Occurs when the retreating cold air mass is colder than the advancing cold air mass
In the initial stage, weather system of the warm front persists. At the later stages the weather conditions resemble those of the cold front.	
Overtaking cold airmass plows under both air masses	Advancing cold air being relatively less dense overrides the retreating cold air mass

Table 6 – Occluded fronts – difference between cold front occlusion and warm front occlusion

7. Cyclones

The atmospheric disturbances which involve a closed circulation about a low pressure centre, anticlockwise in the northern atmosphere and clockwise in the southern hemisphere are called cyclones. They fall into the following two broad categories: (a) Extra-tropical and (b) tropical cyclones.

Student Notes:

7.1. Extra-Tropical Cyclones

Extra-tropical cyclones are the weather disturbances in the mid and high latitude, beyond the tropics. These latitudes are an area of convergence where contrasting air masses generally meet to form polar fronts. The stages of development of extra-tropical cyclone are described below with diagram.

- Initially, the front is stationary (figure 29-1).
- In the northern hemisphere, warm air blows from the south and cold air from the north of the front. When the pressure drops along the front, the warm air moves northwards and the cold air move towards, south setting in motion an anticlockwise cyclonic circulation(figure 29-2).
- The cyclonic circulation leads to a well developed extra tropical cyclone, with a warm front and a cold front (figure 29-3).
- The warm air glides over the cold air and a sequence of clouds appear over the sky ahead of the warm front and cause precipitation (figure 29-4).
- The cold front approaches the warm air from behind and pushes the warm air up (figure 29-5). As a result, cumulus clouds develop along the cold front.
- The cold front moves faster than the warm front ultimately overtaking the warm front. The warm air is completely lifted up and the front is occluded and the cyclone dissipates (figure 29-6).

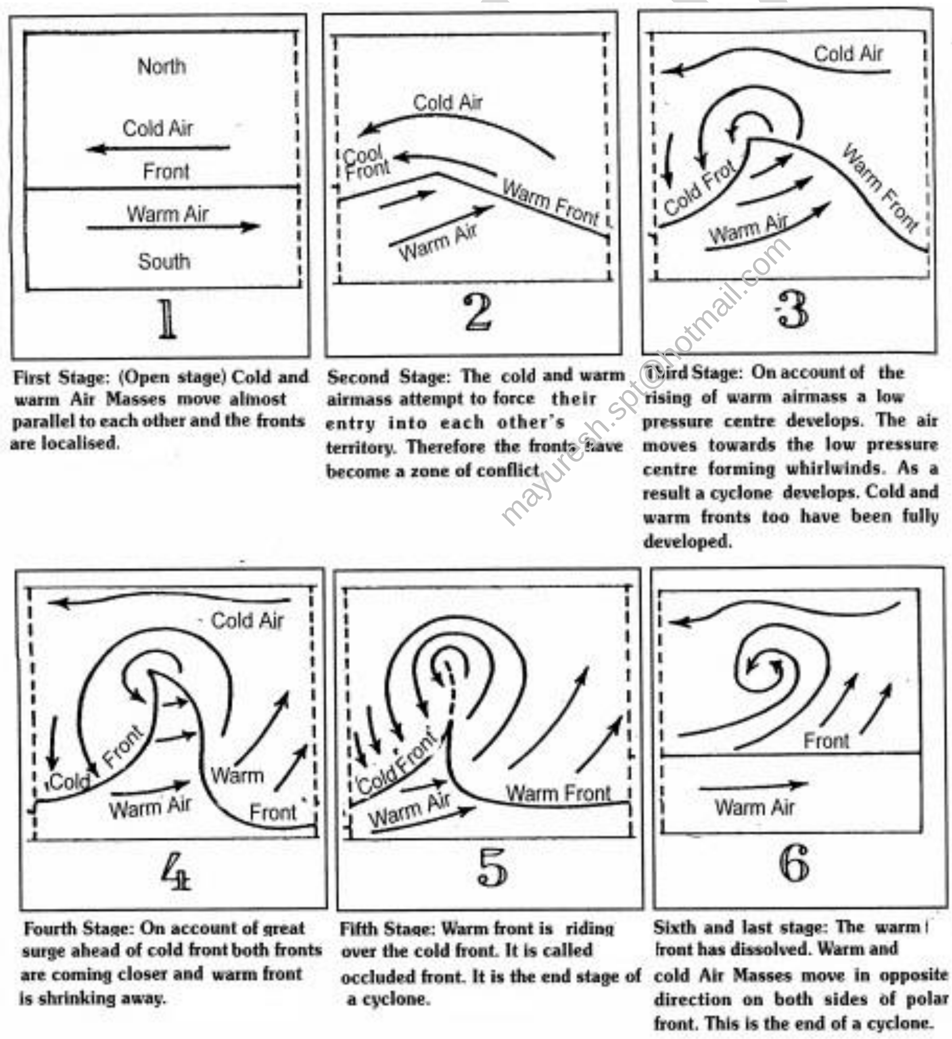


Figure 29 – life cycle of a extra-tropical cyclone

There is great degree of variation in **shape and size** of extra-tropical cyclones. Generally, the isobars are almost circular or elliptical. However, in certain depressions, the isobars take the shape of the letter ‘V’. Such storms are called V-shaped depression. At times, the cyclones become so broad and shallow that they are referred to as troughs of low pressure.

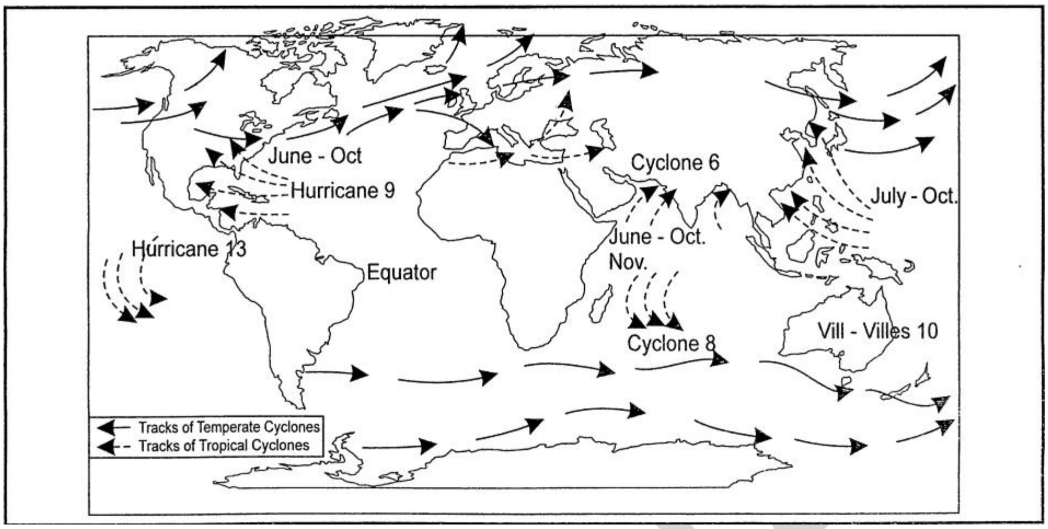


Figure 30 – world: pathways of cyclones (Numbers indicate average frequency of cyclones)

Paths and movement of extra-tropical cyclone – the general direction of movement of temperate cyclones is from west to east with frequent trends towards the southeast to northeast (figure 30). They are subject to the general westerly flow of atmosphere in temperate zone. The heavy concentration of storms tracks in the vicinity of the Aleutian(Islands west to the Alaska Peninsula) and Icelandic lows is the most important feature of the distribution of extra-tropical cyclones. During winter months, the opposing air masses have greater contrasts in their properties. So the winter cyclones are greater in number and are more intense. On an average cyclone may cover a distance of about 1000 km per day. Cyclones invariably move towards higher latitudes.

Secondary cyclones – under the normal conditions, in the later stages of occlusion the cyclone weakens and ultimately dissipates. But sometimes, during the late maturing stage of a cyclone, a new low develops on the equatorward margin of the original cyclone. Thus, a secondary cyclone is formed which passes through different stages of its life cycle and matures very rapidly. It may follow the tract of primary cyclone or may move along new path.

Cyclone families – It is found that an extra-tropical cyclone never appears alone. It is usually followed by three or four cyclones forming a series. The primary or the leading cyclone gets occluded, while the new ones originate on the trailing front and are in an incipient stage. In the rear of the last member of the cyclone family there is an outbreak of polar air which builds up an anti-cyclone. Original cyclone would be in high latitudes and each secondary cyclone would follow progressively a more southerly path. Cyclone families frequent the oceans in a larger number.

Extra-tropical cyclone and Jet stream – there is a close relationship between the flow aloft and the cyclonic storm at the surface. Rossby waves produced at the top of troposphere helps in transporting large bodies of polar air to the lower latitudes and tropical air masses are carried to the higher latitudes. This results in the intensity of surface cyclonic activity. There are instances when extra-tropical cyclones form without the prior existence of a polar front. These depressions are actually initiated by a trough in the upper-air westerlies. Once such storms originate in the lower atmosphere they attract different air masses together which leads to the generation of fronts.

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7.2. Tropical Cyclones

The tropical cyclone develops from the 'warm core' of extremely low pressure area in the tropical oceanic areas. They are energized from the condensation process in the towering cumulonimbus clouds, surrounding the centre of the storm. The arrangement of isobars is almost circular. With continuous supply of moisture from the sea, the storm is further strengthened. On reaching the land the moisture supply is cut off and the storm dissipates. The place where a tropical cyclone crosses the coast is called the **landfall of the cyclone**. The **conditions favourable for the formation** and intensification of tropical storms are:

- Large sea surface with temperature higher than 27° C
- Presence of the Coriolis force
- Small variations in the vertical wind speed
- A pre-existing weak low-pressure area or low-level-cyclonic circulation -
- Upper divergence above the sea level system.

Large and continuous supply of warm and moist air from the ocean provides necessary energy in the form of latent heat of condensation. Coriolis force causes cyclonic circulation. At the equator, the Coriolis force is zero and the wind blows perpendicular to the isobars. The low pressure gets filled instead of getting intensified. That is the reason why tropical cyclones are not formed near the equator.

Because of small variations in the vertical wind speed or wind shear, cyclone formation processes are limited to latitudes equatorword of the sub-tropical jet stream. It is the pre-existing low pressure area which intensifies and develops as cyclone. It must be pointed out that only a few of these disturbances develop into true tropical cyclones. Upper divergence helps in ascending air currents to be pumped out to maintain the low pressure at the centre of the cyclone.

Tropical cyclone shown in figure 31 has following features:

- **Eye** – it is the centre of cyclone around which strong spirally winds circulate in a mature tropical cyclone. It is a region of calm with subsiding air.
- **Eye Wall** – there is a strong spiraling ascent of air to greater height reaching the tropopause. The wind reaches maximum velocity in this region, reaching as high as 250 km per hour. Torrential rain occurs here. From the eye wall rain bands may radiate and trains of **cumulus** and **cumulonimbus** clouds may drift into the outer region.
- The diameter of the circulating system can vary between 150 and 250 km.
- The diameter of the storm over the Bay of Bengal, Arabian Sea and Indian Ocean is between 600 - 1200 km. The system moves slowly about 300 - 500 km per day.

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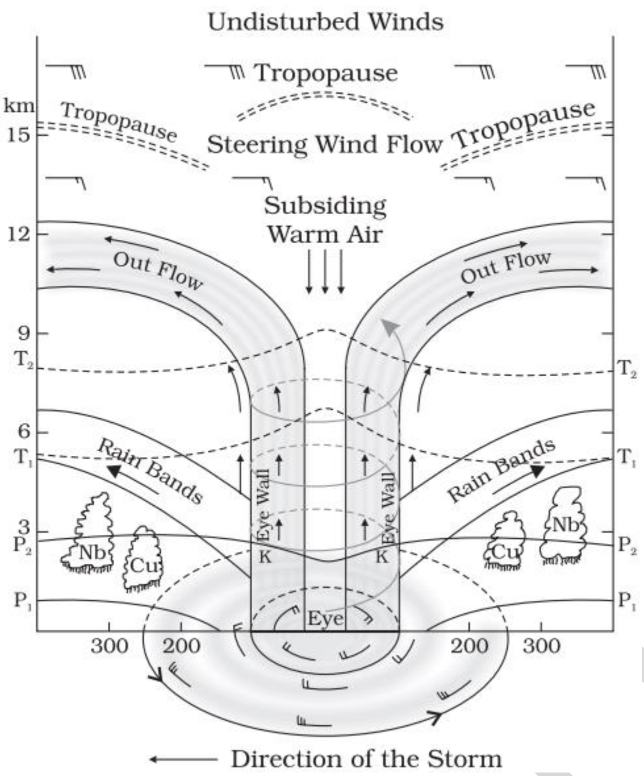

Figure 31 – tropical cyclone

Region	Local name
Indian Ocean	Cyclone or chakrvaat
Atlantic	Hurricanes
Western Pacific and South China Sea	Typhoons
Western Australia	Willy-willies

Figure 32 – different names of tropical cyclone

Impact on humans

- This is one of the most devastating natural calamities. They move over to the coastal areas bringing about large scale destruction caused by violent winds, very heavy rainfall and storm surges.
- The cyclones, which cross 20ºN latitude generally, re-curve and they are more destructive.
- Trees are uprooted and broken and the loose objects swept away.
- A particular location on the land surface encounters opposite winds twice from the circular fashion of the cyclone. These winds create more damage to objects.
- Torrential rains that occur in the towering cumulonimbus clouds inundate the low-lying areas, cause floods and landslides resulting in great loss of life and property damage.
- Strom waves of great heights are great hazard to shipping. These are called storm surge whose height may go up to 20 meters. If cyclone wave combines with the spring tide, the result is disastrous.

Naming of tropical cyclones - In the beginning, storms(tropical cyclone) were named arbitrarily. Then the mid -1900's saw the start of the practice of using feminine names for storms. In the pursuit of a more organized and efficient naming system, meteorologists later decided to identify storms using names from a list arranged alphabetically.

There is a strict procedure to determine a list of tropical cyclone names in an ocean basin(s) by the Tropical Cyclone Regional Body responsible for that basin(s) at its annual/biennial meeting. There are five tropical cyclones regional bodies. The **Regional Specialized Meteorological Centre (RSMC)** – Tropical cyclones is responsible for monitoring and prediction of tropical cyclones over their respective regions. They are also **responsible to name the cyclones**.

In general, tropical cyclones are named according to the rules at a regional level. The **WMO/ESCAP Panel on Tropical Cyclones** at its twenty-seventh Session held in 2000 in Muscat,

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Sultanate of Oman agreed in principal to assign names to the **tropical cyclones in the Bay of Bengal and Arabian Sea**. After long deliberations among the member countries, the naming of the tropical cyclones over north Indian Ocean commenced from September 2004. The list of names India has added to the database includes Agni, Akash, Bijli, Jal (cyclones which have all occurred since 2004). The Indian names in the queue are Leher, Megh, Sagar and Vayu, while those suggested by Pakistan include Nilofar, Titli and Bulbul.

If public wants to suggest the name of a cyclone to be included in the list , the proposed name must meet some fundamental criteria. The name should be short and readily understood when broadcast. Further the names must not be culturally sensitive and not convey some unintended and potentially inflammatory meaning. A storm causes so much death and destruction that its name is considered for retirement and hence is not used repeatedly. Names are usually assigned to tropical cyclones with one-, three-, or ten-minute sustained wind speeds of more than 65 km/h depending on which area it originates.

Importance for naming tropical cyclones:

- It would help identify each individual tropical cyclone.
- It helps the public to become fully aware of its development.
- Local and international media become focused to the tropical cyclone.
- It does not confuse the public when there is more than one tropical cyclone in the same area.
- The name of the tropical cyclone is well remembered by million of people as it is unforgettable event whose name will long be remembered.
- Warnings reach a much wider audience very rapidly.
- It heightens interest in warnings and increases community preparedness.

Difference between extra-tropical cyclone and tropical cyclone is given in table 7 below:

Extra-tropical cyclone	Tropical cyclone
have a clear frontal system and get energy from the horizontal temperature contrasts that exist in the atmosphere	Fronts are not present and get energy from warm and moist air of ocean
Large size (1500-3000km)	Relatively small in size
can originate over the land and sea	originate only over the seas
Travel both on oceans and land	on reaching the land they dissipate.
Affects a much larger area as compared to the tropical cyclone.	
	Wind velocity in a tropical cyclone is much higher and it is more destructive.
move from west to east	move from east to west

Table 7 – comparison between tropical and extra-tropical cyclone

7.3. Thunderstorms and Tornadoes

Unlike Tropical Cyclones, thunderstorms and tornadoes are highly localized weather phenomenon. They are of short duration, occurring over a small area but are violent. They are so small and short lived as to make their prediction very difficult.

A storm accompanied by thunder and lightning is called thunderstorm. It is associated with the cumulonimbus clouds.. Thunderstorms are caused by intense convection on moist hot days. When the clouds extend to heights where sub-zero temperature prevails, hails are formed and they come down as **hailstorm**. If there is insufficient moisture, a thunderstorm can generate

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dust storms. Stages in the development of thunderstorm are described below and shown in figure 33.

1. **Cumulus stage:** Warm, moist air rises in a buoyant plume or in a series of convective updrafts. As this occurs the air begins to condense into a cumulus cloud. As the warm air within the cloud continues to rise, it eventually cools and condenses. The condensation releases heat into the cloud, warming the air. This, in turn, causes it to rise adiabatically. The convective cloud continues to grow upward, eventually growing above the freezing level where super-cooled water droplets and ice crystals coexist Precipitation begins once the air rises above the freezing level.
2. **Mature stage:** it is characterized by the presence of both updrafts and downdrafts within the cloud. The downdrafts are initiated by the downward drag of falling precipitation. Cold descending air in the downdraft will often reach the ground before the precipitation. As the mature-stage thunderstorm develops, the cumulus cloud continues to increase in size, height and width. Cloud to ground lightning usually begins when the precipitation first falls from the cloud base. During this phase of the life cycle, the top of the resulting cumulonimbus cloud will start to flatten out, forming an anvil shape often at the top of the troposphere.

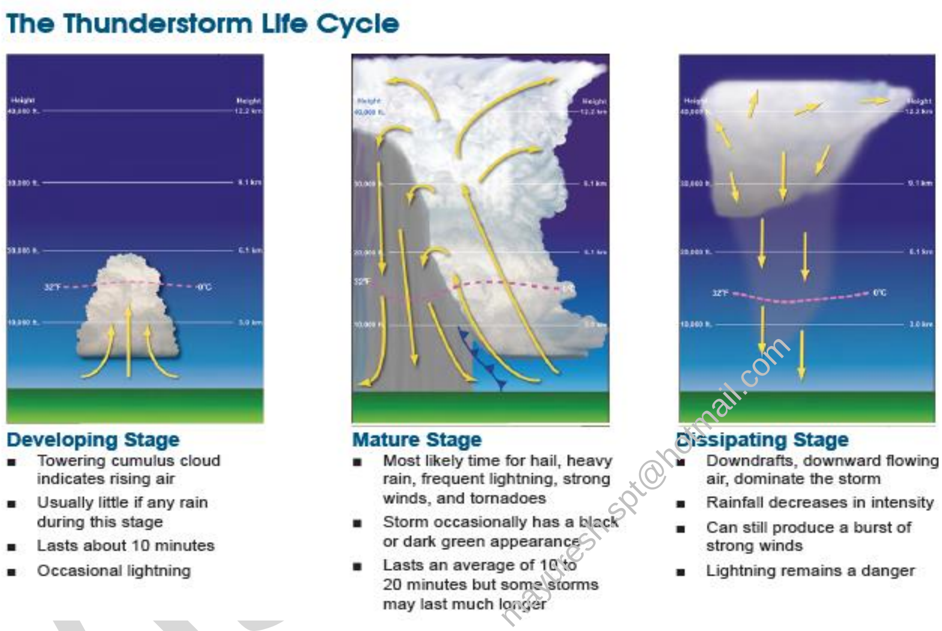

Figure 33 – three stages in the development of a thunderstorm: (a) cumulus stage; (b) Mature stage; (c) Dissipating stage

3. **Dissipating stage:** It is characterized by downdrafts throughout the entire cloud. Decay often begins when the super-cooled cloud droplets freeze and the cloud becomes glaciated, which means that it contains ice crystals. The cloud begins to collapse because no additional latent heat is released after the cloud droplets freeze, and because the shadow of the cloud and rain cooled downdrafts reduce the temperature below the cloud.

7.3.1. What Causes Lightning and Thunder

The rising air in a thunderstorm cloud causes various types of frozen precipitation to form within the cloud. Included in these precipitation types are very small ice crystals and much larger pellets of snow and ice. The smaller ice crystals are carried upward toward the top of the clouds by the rising air while the heavier and denser pellets are either suspended by the rising air or start falling toward the ground. Collisions occur between the ice crystals and the pellets, and these collisions serve as the charging mechanism of the thunderstorm. The small ice

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crystals become positively charged while the pellets become negatively charged. As a result, the top of the cloud becomes positively charged and the middle to lower part of the storm becomes negatively charged. When the strength of the charge overpowers the insulating properties of the atmosphere, lightning happens.

At the same time, the ground underneath the cloud becomes charged oppositely of the charges directly overhead. When the charge difference between the ground and the cloud becomes too large, a conductive channel of air develops between the cloud and the ground, and a small amount of charge (step leader) starts moving toward the ground. When it nears the ground, an upward leader of opposite charge connects with the step leader. At the instant this connection is made, a powerful discharge occurs between the cloud.

The channel of air through which lightning passes can be heated to 50,000°F—hotter than the surface of the sun! The rapid heating and cooling of the air near the lightning channel causes a shock wave that results in the sound we know as "thunder."

7.3.2. Why Thunders are Cause of Concern

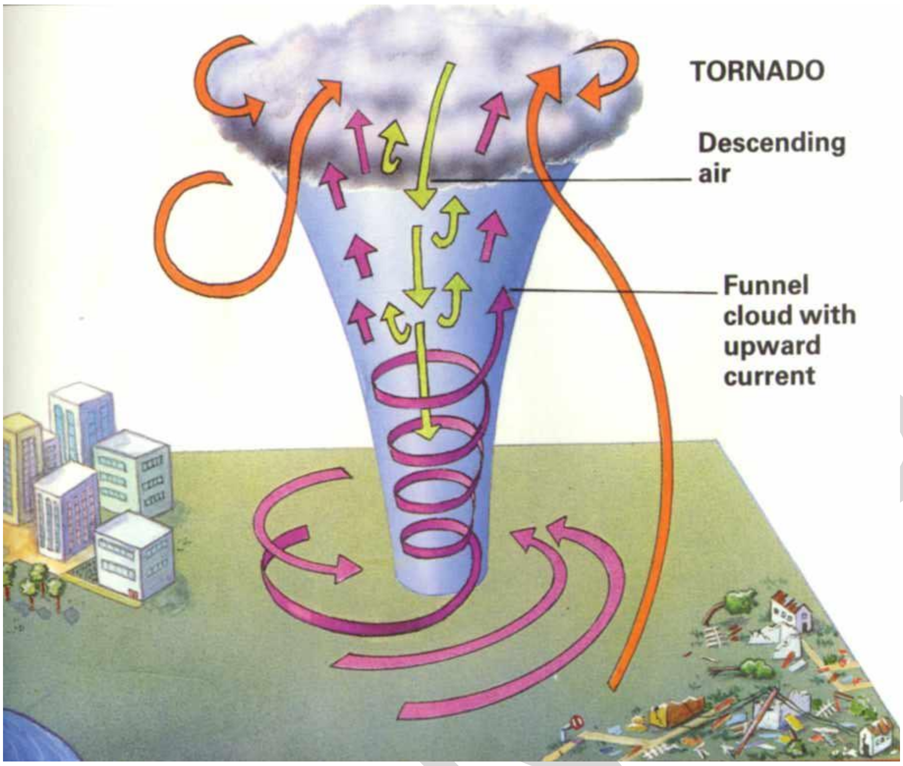
Each year, many people are killed or seriously injured by severe thunderstorms despite the advance warning. While severe thunderstorms are most common in the spring and summer, they can occur at just about any time of the year. Cloud-to-ground lightning, Hail, Tornadoes and waterspouts, Flash flood and Downburst are some of the hazards associated with thunderstorm.

There is no safe place outside during a thunderstorm but building constructed according to current guidance could provide safe seltor and avoid injury or death.

Tornado – From severe thunderstorms sometimes spiraling wind descends like a trunk of an elephant with great force, with very low pressure at the centre causing massive destruction on its way. Such a phenomenon is called a **tornado**. Excessive instability and steep lapse rate in the atmosphere are necessary pre-requisite for the development of a tornado. Tornadoes generally occur in middle latitudes. The tornado over the sea is called **water sprouts**. Chief features of tornadoes are:

- Tornado's funnel can have size of 90-460m in diameter.
- Tornadoes generally occur in middle latitudes.
- Tornadoes are the most violent of all the storms.
- They are very small in size and of short duration which makes weather prediction difficult.
- The velocity of winds revolving tightly around the core reaches more than 300 km per hour.
- It causes massive destruction on its way.
- When looked at from the ground, the funnel appears dark because of the presence of condensed moisture and the dust and debris picked up from the ground by the whirling tornado.
- Tornadoes may be found to be moving singly or in families of several individual tornadoes.
- These generally move in straight paths.

These violent storms are the manifestation of the atmosphere's adjustments to varying energy distribution. The potential and heat energies are converted into kinetic energy in these storms and the restless atmosphere again returns to its stable state.



References:

1. Since sunspots are darker than the surrounding photosphere it might be expected that more sunspots would lead to less solar radiation and a decreased solar constant. However, the surrounding margins of sunspots are brighter than the average, and so are hotter; overall, more sunspots increase the Sun's solar constant or brightness.
2. **Electromagnetic radiation** is a term used to describe all the different kinds of energies released into space by stars such as the Sun.
3. A **photon** is an elementary particle, the quantum of light and all other forms of electromagnetic radiation
4. **Conductor of heat** - Ability to transfer heat to adjacent molecules.
5. The **latent heat of condensation** for water is defined as the heat released when one mole of the substance condenses to form liquid droplets from water vapour. The temperature does not change during this process, so heat released goes directly into changing the state of the substance. The heat of condensation of water is equal to 40.8 kJ/mol. The heat of condensation is numerically exactly equal to the heat vaporization, but has the opposite sign.
6. **Albedo**: it is reflectivity or reflecting power of a surface. It is defined as the ratio of reflected radiation from the surface to incident radiation upon it. Albedos of typical materials in visible light range from up to 0.9 for fresh snow to about 0.04 for charcoal, one of the darkest substances.
7. The **polar front** is the boundary between the polar cell and the Ferrel cell in each hemisphere. At this boundary a sharp gradient in temperature occurs between these two air masses, each at very different temperatures.
8. An **adiabatic process** is a process that occurs without the transfer of heat or matter between a system and its surroundings.

Student Notes:

UPSC Previous Years' Mains Questions

1. The recent cyclone on east coast of India was called 'Phailin'. How are the tropical cyclones named across the world? Elaborate. (100 words)(UPSC 2013/5 marks)
2. What do you understand by the phenomenon of 'temperature inversion' in meteorology? How does it affect weather and the habitants of the place? (100 words) (UPSC 2013/5 marks)
3. List the significant local storms of the hot-weather season in the country and bring out their socio-economic impact. (UPSC 2010/12 Marks)
4. Write about Nor'westers in 20 words. (UPSC 2008/15 Marks)

Student Notes:

PRECIPITATION AND RELATED PHENOMENA

Contents

Student Notes:

1. Introduction

Precipitation is vital for life on Earth, but it can also be an inconvenience. Precipitation is any product of the condensation of atmospheric water vapour that falls under gravity. The main forms of precipitation include drizzle, rain, sleet, snow, graupel and hail. Let us first discuss some basic concepts

2. Water vapour

Water is present in the atmosphere in three forms namely – gaseous, liquid and solid.. The water vapour constitute about 2 per cent of the total composition of the atmosphere. This percentage varies from zero per cent in cold dry air of the Arctic regions during the winter season to as much as 5 per cent of the volume in warm humid equatorial regions.

The temperature of the atmosphere is the most important factor, as the capacity of the warm air to hold water vapour is more than that of the cold air. About half of the total moisture present in the atmosphere is concentrated in the lower layer of the atmosphere up to a height of about 2 kilometres.

2.1. Importance of Water Vapour

The water vapour present in the atmosphere is an important factor for the weather conditions in a particular region. The amount of water vapour present in the atmosphere influences the nature and amount of precipitation, the amount of loss of heat through radiation from the earth's surface, the surface temperature, the latent heat of the atmosphere, the stability and instability of the air masses. Necessary energy for the development of storms (cyclones, hurricanes etc.) is provided by the water vapour in the form of latent heat energy.

3. The Water Cycle

There is a constant and continuous circulation of water from the Earth's surface to the atmosphere and back to the Earth's surface. This circulation of water is called the water cycle or the hydrological cycle. The water cycle has no beginning or end, rather it is an intricate combination of evaporation, transpiration, air mass movement, condensation, precipitation, run-off and groundwater movement.

The Sun's heat provides energy to evaporate water from the Earth's surface (oceans, lakes, etc.). Plants also lose water to the air (this is called transpiration). The water vapor eventually condenses, forming tiny droplets in clouds. When the clouds meet cool air over land, precipitation (rain, sleet, or snow) is triggered, and water returns to the land (or sea). Some of the precipitation soaks into the ground. Some of the underground water is trapped between rock or clay layers; this is called groundwater. But most of the water flows downhill as runoff (above ground or underground), eventually returning to the seas as slightly salty water.

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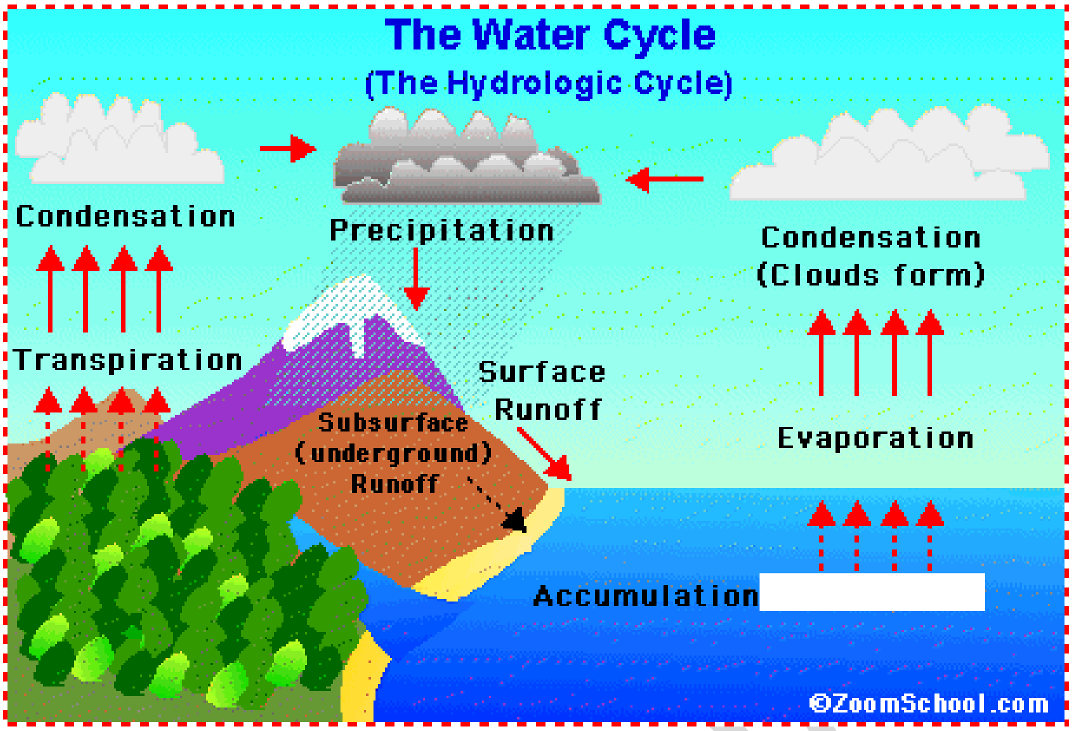

4. Humidity

Humidity refers to the amount of water vapour present in the atmosphere at a particular time and place. Humidity in the air is due to the various processes of evaporation from the land and water surfaces of the Earth. It can be expressed as an absolute, specific or a relative value.

4.1. Absolute Humidity

The Absolute Humidity is the **weight** of actual amount of water vapour present in a **unit volume** of air. Generally it is expressed as **grams per cubic meter** of air. The absolute humidity varies from place-to-place and from time-to-time. It decreases from the equator towards the poles. . Generally, the absolute humidity changes as air temperature or pressure changes. However, if temperature increases but there is no excess water for evaporation then absolute humidity will not change.

4.2. Specific Humidity

The Absolute Humidity is the weight of actual amount of water vapour present in a unit weight of air. Generally it is expressed as grams per kilogram of air.

4.3. Relative Humidity

Relative humidity is a better way of expressing the level of humidity in the air. It is the ratio of actual amount of water vapour present in air at a given temperature to the amount of water vapour air can hold at the same temperature. The Relative Humidity is expressed in percentages.

$$\text{Relative Humidity} = \frac{\begin{array}{c}\text{Absolute Humidity}\\ (\text{Actual amount of water vapour present in the air at a given temperature})\end{array}}{\begin{array}{c}\text{Humidity Retentive capacity}\\ (\text{Amount of water vapour that can be held by the same at the same temperature})\end{array}}$$

Generally capacity to hold water vapour increases with increase in temperature and decreases with decrease in temperature. Thus, the relative humidity of the air decreases with increase in temperature and vice versa Changes in the Relative Humidity of Air[1]

Changes in Relative Humidity can occur in the following three ways:

I. The temperature remaining the same and amount of water vapour in air increases. Its relative humidity will also increase.
II. When the temperature of air rises its humidity retentive capacity also rises correspondingly and the Relative Humidity decreases.
III. If the temperature of air decreases its humidity retentive capacity also decreases and Relative Humidity increases.

4.3.1. Significance of Relative Humidity

The absolute humidity determines the **amount of precipitation** while the relative humidity tells us about the **possibility of precipitation**. The high and low relative humidity indicates the possibility of wet and dry conditions respectively. Evaporation decreases when there is high relative humidity and vice versa. Relative humidity is directly related to human health. That is why, the equatorial region with high temperature and high relative humidity, and the tropical hot deserts with very low relative humidity are unfavourable for human health.

Absolute Humidity	Relative Humidity
It helps us to know the actual amount of water vapour present in air.	It shows the ratio of water vapour actually present in the air at a given temperature to the retentive capacity of humidity of the same parcel of air at the same temperature.
It does not take temperature into account.	It takes temperature into account.
It is expressed in grams per cubic metre.	It is expressed in percentages.
It Is not a useful measure of humidity because it does not tell us the amount of water vapour required for the air to become saturated.	It is a useful measure of humidity because it can show how far the air is humid.

4.3.2. The Horizontal Distribution of Relative Humidity

The equatorial region is characterized by the highest relative humidity. Relative humidity gradually decreases towards the Tropical high pressure belts (between 25°—35° latitudes) . After this, the relative humidity again increases polewards. The zones of high and low relative humidity shift northward and southward with the apparent migration of the Sun, during the summer and winter solstices respectively. **Relative humidity is maximum in the mornings and minimum in the evenings.**

5. Evaporation

The process of transformation of liquid (water) into gaseous form (water vapour) is called evaporation. The amount and rate of evaporation at a particular place depend upon the aridity

[1] If any question based on change of a property(say temperature) is asked consider other factors (say moisture) as constant unless otherwise specified.

(vapour pressure), temperature and the movement of air. Evaporation is faster in dry air than in the wet air. There is more evaporation from the ocean than from the land. A special case of evaporation is **transpiration** which entails loss of water from the leaves and stems of the plants.

6. Condensation

The process of transforming of water vapour into water (liquid) and ice (solid) is called condensation. Condensation takes place due to the loss of heat and can occur in one of the following ways: a. When the warm moist air rises upwards and expands. b. When the warm moist air comes in contact with the cold surface. c. When the warm moist air mixes with the air coming from the colder regions.

6.1. Latent Heat

At the time of evaporation, heat is absorbed and conserved in water vapour (This is why Evaporation leads to cooling). It is known as latent heat. It is this same heat which is released when water vapour again changes into water through the process of condensation. Latent heat is essential for development of typhoons (storms, cyclones).

6.2. Saturated Air

If at any given temperature the humidity retentive capacity of air equals its absolute humidity the air is said to be saturated. In other words the same parcel of air can no longer absorb or accept any further amount of water vapour at the same temperature. 100 per cent humid air is called saturated air.

6.3. Hygroscopic Nuclei

Condensation always takes place around some particles present in air. These may be dust particles, smoke, oceanic salts or carbon dioxide which act as nuclei to hold water. They are thus called condensation nuclei or hygroscopic nuclei.

6.4. Dew point

Condensation of water vapour in the atmosphere begins when the saturated air mass reaches the dew point. This is level at which the air is not in a position to take up any more moisture. Any further fall in temperature, beyond the dew point, would cause the condensation of the moisture present in the air. In the atmosphere, the nuclei for the condensation of the moisture is provided by the smoke and the dust particles.

Once the condensation of water vapour in the atmosphere has taken place, the moisture present in the atmosphere may take one of the following forms— dew, frost, fog, mist, clouds, etc. This will be according to the conditions prevalent in the atmosphere.

7. Dew

When the relative humidity of the air is low, even a drop in temperature during the winter nights fails to saturate the air. Hence condensation does not take place in free air but on some solid objects like leaves, flowers, grass blades, pieces of rocks, etc., which become comparatively cool due to the quick radiation at night. When the cool air comes in contact with these objects, the dew point is reached and condensation takes place. The deposition of water droplets on these objects is called ***dew.***

Some favourable conditions for the formation of dew are the following:

1) **Long Nights**: During long nights earth's surface is cooled. With the coming into contact of humid air with this surface, condensation occurs.

2) **Cloudless Clear Sky**: On account of cloudless and clear sky there is more heating during the day. Hence evaporation will also be more and also rapid cooling of surface at night due to terrestrial radiation.
3) **Calm Air**: Calm air remains in contact with the surface for longer duration. It is a favourable condition for condensation.
4) **Relative Humidity**: High relative humidity promotes more condensation. That is why condensation can be more in the months of August -September in India.

8. Frost

Frost is actually frozen dew. It is formed when temperature of dew point fall below freezing point. Under such conditions droplets of condensation near or on the ground are frozen. Generally for formation of dew and frost the conditions are similar. Only temperature should fall below freezing point for the formation of frost

Dew	Frost
It can be seen as droplets of water on leaves of small plants or blades of grass.	It can be found on solid surfaces of earth's crust as ice or snow crystal.
It Is formed when temperature of dew point is above freezing point.	It is formed when temperature is below freezing point.
It is useful for plants.	It is harmful for plant growth.

9. Fog

Fog is a special type of thin cloud consisting of very small water droplets which remain suspended in air close to the surface of the Earth. Fog is formed due to condensation of water droplets suspended in the atmosphere in the vicinity of the earth's surface under certain conditions, such as low temperature and high relative humidity.. During the winter season, excessive radiation at night results in the fall of air temperature. The condensation of water vapour takes place around the dust and smoke particles that remain suspended in the air. It is called **fog.** The formation of fog near the surface of the Earth does not involve ascent and consequent expansion of air. The visibility is greatly reduced (less than one km).

Fog is of three types:

1) **Radiation Fog:** The surface is cooled at night due to terrestrialradiation and the air which come into contact with it also gets cooled. Consequently tiny droplets forming the clouds are called radiation fog. It is not very thick and this thickness varies from 10 to 30 metres.
2) **Advection Fog:** It is formed when there is fall in temperature of warm moist air moving horizontally over a cold surface. It is cooled by contact and sometimes by mixing with cold air prevailing over cold surfaces.
3) **Frontal or Precipitation Fog:** The dividing line separating cold and warm air masses are known as fronts. At these fronts convergence of warm and cold air takes place and fog is formed. The warm air in the frontal area is light and rises above the cold air mass. It then begins to cool and when the temperature reaches dew point, frontal fog is formed.

9.1. Impact of Fog

Fog hinders travel by land, air and sea. When the fog is polluted it becomes poisonous and causes serious health hazards. Agriculture sector is also affected since fog adversely hits late-sowing crops. Fog is beneficial to the tea and coffee plants as it protects them from the scorching sunlight on the hill slopes.

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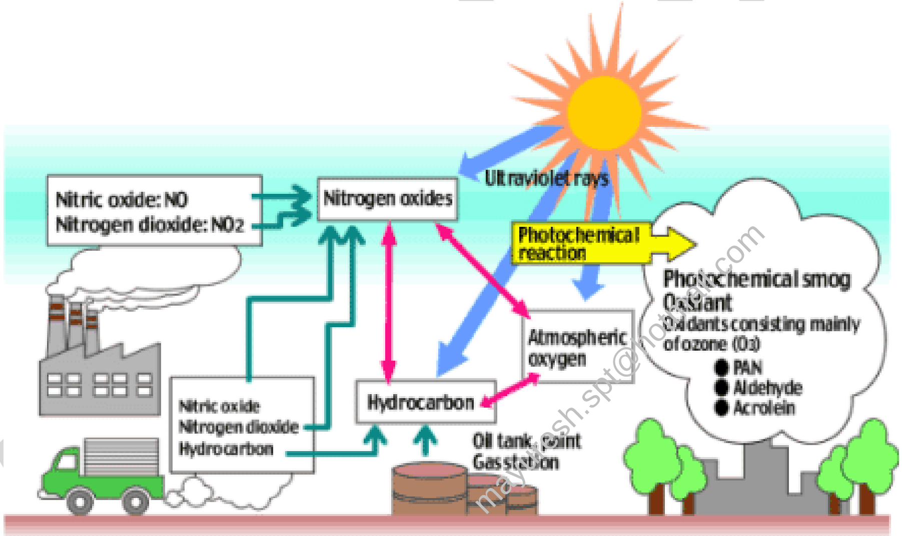
10. Mist

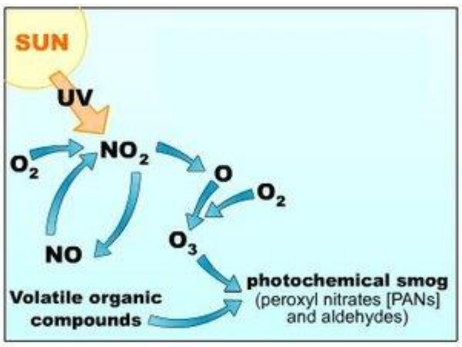
It is also a type of fog but is relatively less dense. The only difference between mist and fog is density and its effect on visibility. A cloud that reduces visibility to less than 1 km is called fog, whereas it's called mist if visibility range is between 1 and 2 km. Mists are frequent over mountains as the rising warm air up the slopes meets a cold surface. Fogs are drier than mist and they are prevalent where warm currents of air come in contact with cold currents. Mist can occur as part of natural weather or volcanic activity or could be created artificially.

11. Smog

It refers to a mixture of smoke and fog. It also results from sun's effect on certain pollutants in the air, notably those from automobile exhaust. There are two main types of smog—photochemical and industrial.

The **photochemical smog** is a mixture of primary and secondary pollutants. The primary pollutants are hydrocarbons and **nitrogen oxides** and their main source is the motor vehicles. The secondary pollutants are formed when sunlight acts upon motor vehicle exhaust gases to form harmful substances such as ozone (O3), aldehydes and peroxyacetylnitrate (PAN). Photochemical smog formation requires (1)a still, sunny day and (2)temperature inversion (pollutants accumulate in the lower inversion layer). The photochemical smog directly affect lungs and eyes, causing irritation in these organs.





FORMATION OF PHOTOCHEMICAL SMOG

The **industrial smog** is a mixture of sulphur dioxide and a variety of solid and liquid particles suspended in air.It comes from the stationary sources, such as furnaces, power plants, etc., than from motor vehicles. Sulphur dioxide in combination with water and oxygen can turn into sulphuric acid in the atmosphere and falls on the earth as acid rain. It can dissolve marble and eat away iron and steel. In human it can affect the respiratory system.

Name:	**Industrial smog** (New York smog, gray smog)	**Photochemical smog** (Los Angeles smog, Denver smog, brown smog)
Weather:	cool, damp	sunny
Content:	particulates, sulfur oxides	NO_x, ozone, hydrocarbons, PAN
Sources:	coal, etc.	gasoline(Petrol), combustion.

12. Haze

is traditionally an atmospheric phenomenon where dust, smoke and other dry particles obscure the clarity of the sky. The World Meteorological Organization manual of codes includes a classification of horizontal obscuration into categories of fog, ice fog, steam fog, mist, haze, smoke, volcanic ash, dust, sand and snow. Sources for haze particles include farming (ploughing in dry weather), traffic, industry, and wildfires. One way to distinguish between smog and naturally-occurring haze is by color. Natural haze is typically white, gray or even blue. Smog is almost always yellowish or brown in color.

The international definition of fog is a visibility of less than 1 kilometre; mist is a visibility of between 1 kilometre and 2 kilometres and haze from 2 kilometres to 5 kilometres . Fog and mist are generally assumed to be composed principally of water droplets, haze and smoke can be of smaller particle size.

13. Atmospheric Brown Cloud (ABC)/Asian Brown Cloud

The ABC originally referred to the enormous blanket of pollution spreading across Asia, distorting normal weather patterns in the region and threatening to devastate many countries' economies. It was called the 'Asian Brown Cloud' in 2002, when a UN report first warned of this layer of pollution comprising ash, acids and aerosols. At that time, the two-mile thick haze extended ominously across the most densely populated areas of the world: southern, south-eastern, and eastern Asia. Subsequently, however, similar patterns were detected elsewhere in the world and it was renamed 'Atmospheric Brown Cloud'.

Asia is particularly vulnerable as the ABC causes changes in the winter monsoon season, sharply reducing rain over northwestern parts of the continent and increasing rain along the eastern coast. However, India's scientific community have said the atmospheric brown clouds over Asia are a seasonal, temporary phenomena which may look bad, but have none of the catastrophic implications mentioned in the UN report.

14. Clouds

When the moist air ascends, it expands, loses temperature, becomes cool, and gets saturated. With further decrease in temperature beyond the dew point, condensation of the moisture takes place high up in the air and it results in the formation of clouds. **Clouds are droplets of water or tiny ice crystals which collect around the dust particles present in the atmosphere**. The water droplets and tiny ice crystals that remain suspended in the air can be disturbed by the slightest movement of the air. **All forms of precipitation occur from the clouds**. It should be noted that **not all clouds yield precipitation but no precipitation is possible without the**

clouds. The clouds play a major role in the heat budget of the Earth and the atmosphere, as they reflect, absorb and diffuse some part of the incoming solar radiation. They also absorb a part of the outgoing terrestrial radiation and then re-radiate it back to the Earth's surface. Whenever there are clouds in the sky, some sort of precipitation always occurs, although we do not feel it on the Earth. Much of it is re-evaporated during its descent through the warm and dry air. Clouds are more common on the windward slopes of the mountains than on the leeward slopes. Clouds are more frequent during the cyclones than during the anticyclones.

15. Types of Clouds

Luke Howard, an English biologist, was the first to classify clouds in 1803. He used Latin names which are still in vogue. Clouds are usually classified on the basis of altitude, shape, expanse, density, colour, transparency, opaqueness, moisture content, etc. They exist at various elevations from the sea level to about 20 km above the sea level. There are three basic groups depending upon the height and shape of clouds. These are the **cirrus clouds**, the **cumulus clouds** and the **stratus clouds**.

15.1. Cirrus (Curl of Hair) Clouds

Cirrus clouds are formed at high altitudes (8,000 - 12,000m). Being at considerable height these clouds are formed of **ice crystals** and therefore are **white** and **thin**. They are detached, fibrous, **feathery**, often with silky sheen in direct sunlight.

15.2. Cumulus (Heap) Clouds

Cumulus clouds look like cotton wool. They are generally formed at a height of 4,000 -7,000 m. They exist in patches and can be seen scattered here and there. With a flat base on rising they appear like domes at the top. Their appearance and structure is like that of a Cauliflower.

15.3. Stratus (Layer) Clouds

As their name implies, these are layered clouds covering large portions of the sky. These clouds are generally formed either due to loss of heat or the mixing of air masses with different temperatures.

The rain bearing clouds are generally the low level clouds and are given the prefix or suffix- 'nimbus', a Latin word meaning a rainy cloud.

Note: Whichever clouds you see in the sky these might be one or more of their types or their combinations or even in changed appearances.

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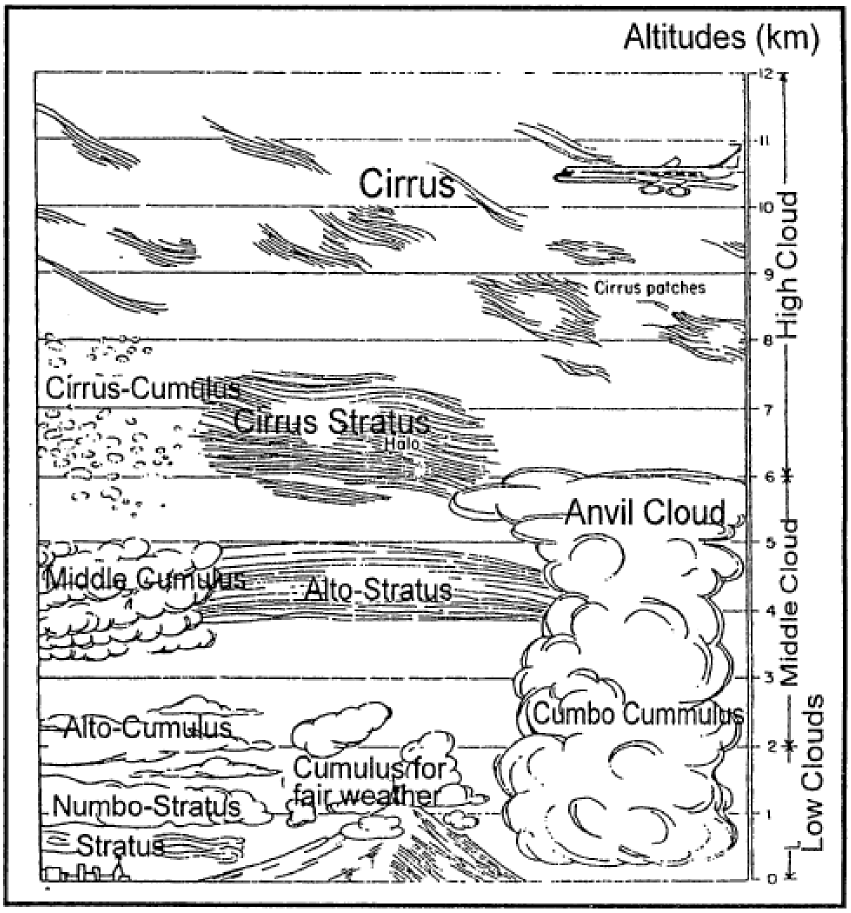
16. International Classification of Clouds

The World Meteorological Organisation presented a detailed International Atlas of Clouds mentioning three main groups and ten main types of clouds.

Cloud Group	Height in meters	Cloud Types	
High Clouds = **Cirrus**	6000-12000	1. Cirrus 2. Cirrostratus[2] 3. Cirrocumulus	High-level clouds form above 6,000 meters and since the temperatures are so cold at such high elevations, these clouds are primarily composed of ice crystals. High-level clouds are typically thin and white in appearance, but can appear in a magnificent array of colors when the sun is low on the horizon.
Middle Clouds = **Alto**	2000-6000	4. Altostratus 5. Altocumulus	The bases of mid-level clouds typically appear between 2,000 to 6,000 meters. Because of their lower altitudes, they are composed primarily of water droplets, however, they can also be composed of ice crystals when temperatures are cold enough.
Low Clouds = **Stratus**	below 2000	6. Stratus 7. Stratocumulus 8. Nimbostratus	Low clouds are of mostly composed of water droplets since their bases generally lie below 2,000 meters. However, when temperatures are cold enough, these clouds may also contain ice particles and snow.
Clouds with Vertical Growth	9. Cumulus 10. Cumulonimbus		Probably the most familiar of the classified clouds is the cumulus cloud. Generated most commonly through either thermal convection or frontal lifting, these clouds can grow to heights in excess of 12,000 meters, releasing incredible amounts of energy through the condensation of water vapor within the cloud itself.
Special Clouds	Mammatus Lenticular Fog Contrails		

[2] Sun's Halo is produced by the ice crystals in cirrostratus clouds high (5–10 km) in the upper troposphere.



17. Precipitation

The process of continuous condensation in free air helps the condensed particles to grow in size. When the resistance of the air fails to hold them against the force of gravity, they fall on to the earth's surface. So after the condensation of water vapour, the release of moisture is known as *precipitation*. This may take place in liquid or solid form. The precipitation in the form of water is called ***rainfall***, when the temperature is lower than the 0^0C, precipitation takes place in the form of fine flakes of snow and is called ***snowfall***. Moisture is released in the form of hexagonal crystals. These crystals form flakes of snow. Usually the amount of snowfall is included in the rainfall figures. Besides rain and snow, other forms of precipitation are *sleet* and *hail*, though the latter are limited in occurrence and are sporadic in both time and space.

Sleet: Snow is not frozen rain. The term **sleet** is used for the frozen raindrops and the re-frozen melted snow water in the cold layer of the air near the Earth's surface. Sleet also refers to a mixture of snow and rain.

Hailstones: Sometimes, drops of rain after being released by the clouds become solidified into small rounded solid pieces of ice and which reach the surface of the earth are called *hailstones*.

Hailstone mostly in the cumulo-nimbus clouds. Small droplets of water are formed in the lower part of the clouds due to condensation. Many of these small droplets join together to form large ones. The strong rising convection current carries these raindrops to the higher levels, which causes freezing and gives rise to small ice pellets. The strength of the vertical current is highly variable. Thus the ice pellets are not taken up continuously. They fall for some distance, slightly melt at the lower levels and are carried up again. This happens several times until the weight of the ice pellets becomes so heavy that they cannot be carried up by the current. Ultimately these ice pellets fall as hailstones on the Earth. Hailstones have several concentric

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layers of ice one over the other. The size of the halistones depends upon the amount of ice it collects during its ascent and descent in the atmosphere by the convection current.

Hailstones occur widely in the world, except in the polar regions, the hot deserts and the equatorial region. The occurrence of hailstones is common during the spring and the early summer in the sub tropical and the temperate regions.

18. Necessary Conditions for RAINFALL

(a) there should be sufficient amount of evaporation from the water bodies (airmass must be saturated with water vapour)
(b) there should be wind to carry the water vapour from one place to another, and
(c) there should be some way of decreasing the temperature of the moist air.

The rainfall does not occur unless these cloud droplets become so large that the air is not able to hold them in suspension. Rainfall occurs only when the cloud droplets change to raindrops. The diameter of a raindrop is about 5 mm and one raindrop contains about 8 million cloud droplets.

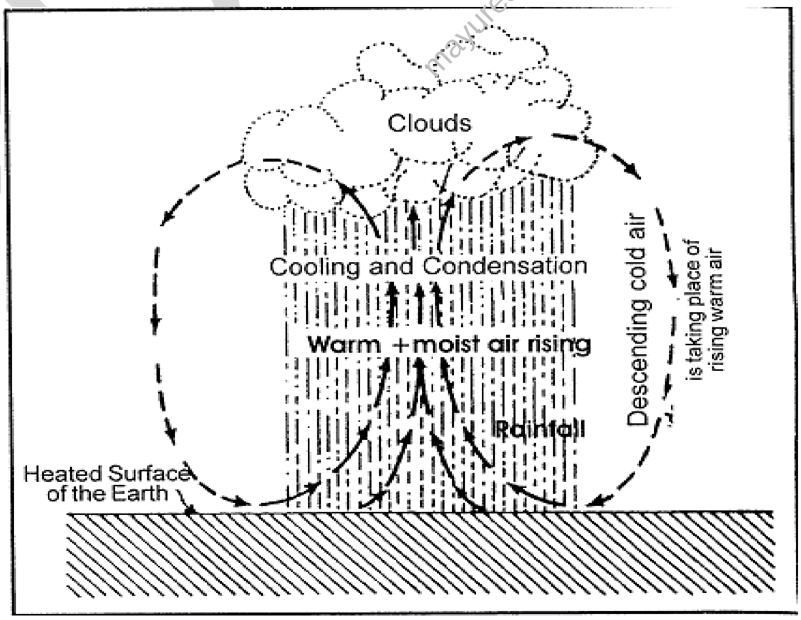
19. Types of Rainfall

According to the way, the cooling of the warm moist airmass takes place, the rainfall can be of the following three types: -

19.1. Convectional Rainfall

As it rises, it expands and loses heat and consequently, condensation takes place and cumulous clouds are formed. With thunder and lightening, heavy rainfall takes place but this does not last long. Such rain is common in the summer or in the hotter part of the day. It is very common in the equatorial regions and interior parts of the continents, particularly in the northern hemisphere.

In the equatorial regions convectional rainfall is received almost daily in the afternoons. In these regions ground starts heating up early morning and by afternoon convectional currents start rising. The whole sky soon is overcast with clouds. Late in the afternoon thunderstorms and lightning occur. It generally happens regularly at 4 P.M. throughout the year. For this reason it is also called 4'O clock rainfall.

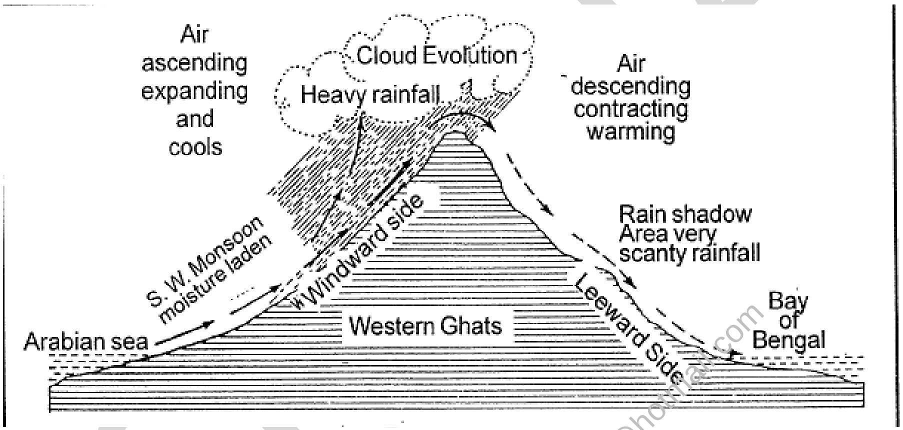


19.2. Orographic Rain

It is also known as the relief rain. When the saturated air mass comes across a mountain, it is forced to ascend and as it rises, it expands; the temperature falls, and the moisture is condensed. The chief characteristic of this sort of rain is that the windward slopes receive greater rainfall. After giving rain on the windward side, when these winds reach the other slope, they descend, and their temperature rises. Then their capacity to take in moisture increases and hence, these leeward slopes remain rainless and dry. The area situated on the leeward side, which gets less rainfall is known as the rain-shadow area. For example, Mahabaleshwar lying on the windwardside of Western Ghats receives annual rainfall of about 622 cm as against Pune on the leeward side only 70 km away from Mahabaleshwar receives only 66 cm annual rainfall.

The windward slope of a mountain, at the time of rainfall, has cumulus clouds while the leeward slope has stratus clouds. The orographic rainfall may occur in any season. It is longer duration. The orographic rainfall is supported by convectional and cyclonic processes of condensation. Most of the precipitation in the world is orographic in nature.

In India, Cherrapunji in Meghalaya plateau, the Western Ghats and the entire Himalayan region receive Orographic Rainfall.



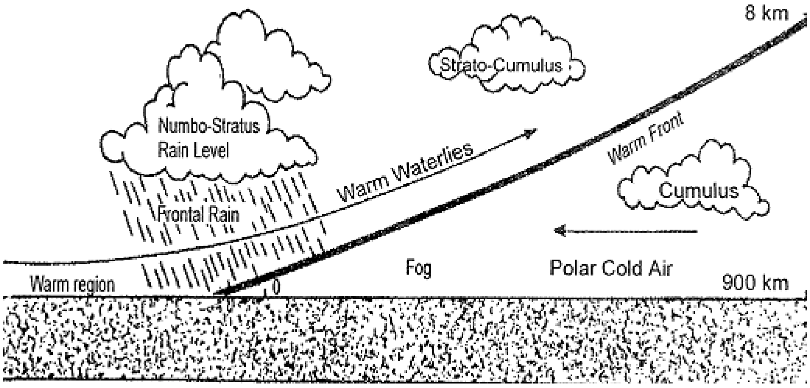
19.3. Cyclonic or Frontal Rainfall

Cyclones have low pressure at the centre, surrounded by high pressure. When wind from all directions blow towards centre, air masses of different characteristics meet creating fronts. The warm air being the lighter, rises above the cold air. The rising warm air cools and condensation takes place, causing rainfall.

This type of rainfall is associated with temperate and tropical cyclones. Since the lifting of warm air along the warm front of the temperate cyclone is slow and gradual, the condensation is also slow and gradual. Thus the precipitation occurs in the form of **drizzle**[3], It is widespread and continues for a longer duration. Most of the rainfall in the temperate region is received through frontal or cyclonic rains.

The tropical cyclone, regionally known as typhoons, hurricanes, tornadoes, etc., yield heavy downpour in China, Japan, Southeast Asia, India, USA, etc.

[3] When the drops of rain are very small, it is called drizzle.



20. Distribution of Precipitation

The mean annual rainfall on Earth is about 100 cm but different places on the earth's surface receive different amounts of rainfall in a year and that too in different seasons. **Factors** controlling the distribution of rainfall over the earth's surface are the belts of converging-ascending **air flow** (doldrums; polar front etc.), air **temperature**, **moisture**-bearing winds, ocean currents, **distance inland** from the coast, and **mountain ranges**. In general, as we proceed from the equator towards the poles, rainfall goes on decreasing steadily. The coastal areas of the world receive greater amounts of rainfall than the interior of the continents. The rainfall is more over the oceans than on the landmasses of the world because of being great sources of water. Between the latitudes 350 and 400 N and S of the equator, the rain is heavier on the eastern coasts and goes on decreasing towards the west. But, between 450 and 650 N and S of equator, due to the westerlies, the rainfall is first received on the western margins of the continents and it goes on decreasing towards the east. Wherever mountains run parallel to the coast, the rain is greater on the coastal plain, on the windward side and it decreases towards the leeward side.

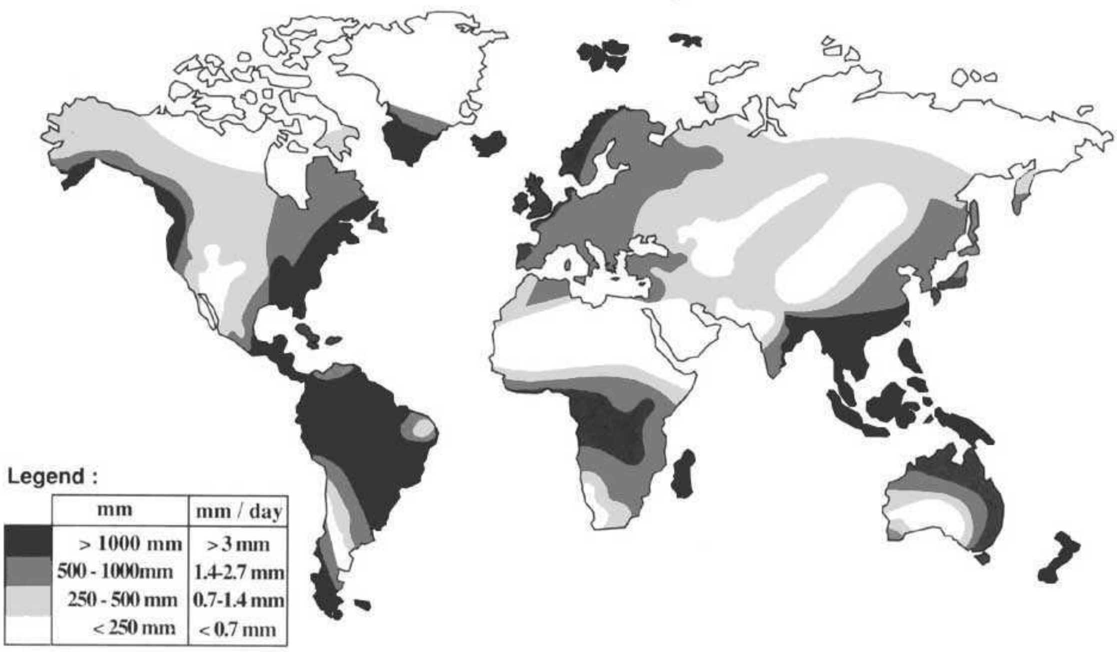
On the basis of the total amount of annual precipitation, major precipitation regimes of the world are identified as follows.

Areas of Heavy Rainfall: The regions receiving more than 200 cm of annual precipitation are included in this belt. The main areas are the **equatorial belt**, the mountain slopes along the western coasts in the cool temperate zone and the coastal areas of the monsoon lands.

Areas of Moderate Rainfall: The regions receiving 100 cm to 200 cm of annual precipitation are included in this belt. The main areas lie adjacent to the regions of heavy rainfall. The coastal areas in the warm temperate zone also receive moderate precipitation.

Areas of Low Rainfall: The regions receiving 50 cm to 100 cm of annual precipitation are included in this belt. The main areas lie in the central part of the tropical lands and in the eastern and the interior parts of the temperate lands.

Areas of Scanty Rainfall: The regions receiving less than 50 cm of annual precipitation are included in this belt. The main areas are the rain shadow areas on the leeward slopes of the mountain ranges, the interior of the continents, the lands in the high latitudes, western margins of the continents in the tropical areas and the arid deserts.



20.1. Seasonal Distribution of Rainfall

The conditions, which can cause precipitation, do not exist in the same combination throughout the year. This leads to the variations in the seasonal distribution of rainfall. However, most of the areas in the world receive a major part of the precipitation during the summer season.

The main characteristics of the seasonal distribution of rainfall

- Heavy rainfall occurs throughout the year in the equatorial region.
- A few degrees north or south of the equator have wet summers and dry winters.
- The monsoon circulation brings more seasonal contrasts resulting in wet summers, as the wind blows onshore, and dry winters as the wind blows offshore.
- Seasonal variation, due to the monsoons, is well-developed in the Indian Subcontinent and in Southeast Asia.
- Most of the western coastal areas in the mid- latitudes have dry summers and wet winters due to the presence of the sub-tropical high pressure belts.
- In the temperate region the precipitation is cyclonic in nature and the cyclones are more common in the winter season. Thus heavy rainfall occurs in winters and not in summers.

The monthly distribution of precipitation throughout the year is often more significant than the average annual precipitation because rainfall is important for the various human activities, especially agriculture. The dependence on rainfall is a matter of great concern to farmers in the sub-humid and semi-arid lands where any departure from the normal regime may result in crop failure.

Student Notes:

21. Prelims Questions

Clouds

1. Which one of the following statements is correct?
(a) Circus clouds are composed office crystals
(b) Cirrus clouds exhibit a flat base and have the appearance of rising domes
(c) Cumulus clouds are white and thin and form delicate patches and give a fibrous and feathery appearance
(d) Cumulus clouds are classified as high clouds. **(2004)**

2. Sun's halo is produced by the refraction of light in
(a) Water vapour in Stratus clouds
(b) Ice crystals in Cirro-Cumulus clouds
(c) Ice crystals in Cirrus clouds
(d) Dust particles in Stratus clouds **(2004)**

Precipitation: Distribution

3. **"Assertion (A):** Bangalore received much higher average rainfall than that of Mangalore.
Reason (R): Bangalore has the benefit of receiving rainfall both from south – west and north – east monsoons." **(2004)**

4. **"Assertion (A):** The eastern coast of India produces more rice than the western coast.
Reason (R): The eastern coast receives more rainfall than the western coast." **(2003)**

OCEAN BASICS AND OCEAN RESOURCES

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1. Ocean Basics

Water is an essential component of all life forms. The earth fortunately has an abundant supply of water on its surface. Hence, our planet is called the **Blue Planet**. About *97 per cent* of the planetary water is found in the oceans. Oceans account for more than 70 per cent or 140 million square miles of the earth's surface.

Oceanography, the science of the oceans, has become such an important subject in recent years and many researches into the deep seas have been conducted. The oceans, unlike the continents, merge so naturally into one another that it is hard to demarcate them. The geographers have divided the oceanic part of the earth into **four** oceans, namely the **Pacific**, the **Atlantic**, the **Indian** and the **Arctic**.

1.1. Relief of the Ocean Floor

Ocean Floor refers to the land under the waters of the oceans. The ocean floor exhibits complex and varied features similar to those observed over the land. The floors of the oceans are rugged with the world's largest mountain ranges, deepest trenches and the largest plains. These features are formed, like those of the continents, by the factors of *tectonic*, *volcanic* and *depositional* processes.

The ocean floors can be divided into following four major divisions:

1.1.1. Continental Shelf

The continental shelf is the extended margin of each continent occupied by relatively shallow seas. It is the shallowest part of the ocean showing an average gradient of1° or even less. The shelf typically ends at a very steep slope, called the **shelf break**.

The widths of the continental shelves vary from one ocean to another. The average width of continental shelves is about 80 km. The shelves are almost absent or very narrow along some of the margins like the coasts of Chile, the west coast of Sumatra, etc. On the contrary, **the Siberian shelf** in the Arctic Ocean, the largest in the world, stretches to 1,500 km in width. The depth of the shelves also varies. It may be as shallow as 30 m in some areas while in some areas it is as deep as 600 m.

The continental shelves are covered with variable thicknesses of sediments brought down by rivers, glaciers, wind, from the land and distributed by waves and currents. Massive sedimentary deposits received over a long time by the continental shelves, become the source of fossil fuels.

1.1.2. Continental Slope

The continental slope connects the continental shelf and the ocean basins (bottom of the ocean). It begins where the bottom of the continental shelf sharply drops off into a *steep slope*. The gradient of the slope region varies between 2-5°. The depth of the slope region varies between 200 and 3,000m. The slope boundary indicates the end of the continents. *Canyons* and *trenches* (discussed later in minor relief features of ocean floor) are observed in this region.

1.1.3. Continental Rise

Where the continental slope ends, the gently sloping continental rise begins. Its general relief is low and with increasing depth, the continental rise becomes virtually flat to merge with the deep sea plains.

1.1.4. Deep Sea Plain

Deep sea plains are gently sloping areas of the ocean basins. These are the flattest and smoothest regions of the world. The depths vary between 3,000 and 6,000m. These plains are covered with fine-grained sediments like clay and silt.

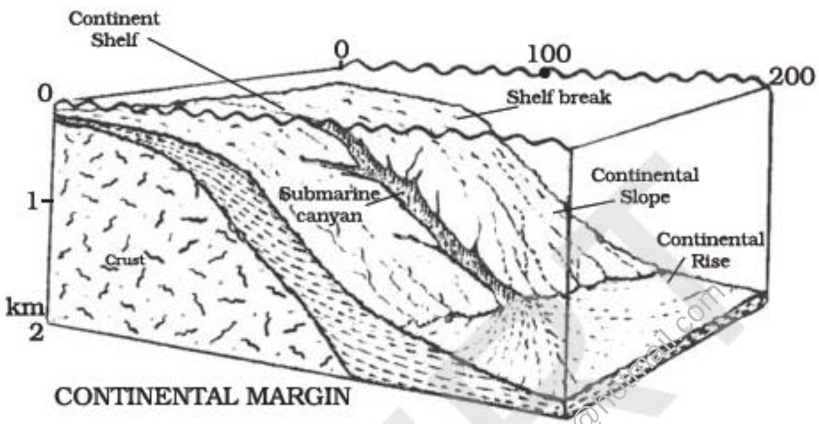
Deep sea plains cover two-thirds of the ocean floor and are also known as **abyssal plains**. They also contain features like ridges, guyots and oceanic islands that sometimes rise above the sea level in the midst of oceans.

1.1.5. Oceanic deeps or Trenches

These areas are the deepest parts of the oceans. The trenches are relatively steep sided, narrow basins. They are some 3-5 km deeper than the surrounding ocean floor. They occur at the bases of continental slopes and along island arcs and are associated with *active volcanoes* and *strong earthquakes*. That is why they are very significant in the study of plate movements.

As many as 57 deeps have been explored so far; of which 32 are in the Pacific Ocean; 19 in the Atlantic Ocean and 6 in the Indian Ocean. The greatest known ocean deep is the **Mariana Trench** near *Guam Island*, which is more than 36,000 feet deep.

Figure 1. Major relief features of the ocean floor.



1.2. Minor Relief Features of the Ocean Floor

Apart from the above mentioned major relief features of the ocean floor, following minor but significant features predominate in different parts of the oceans:

1. **Mid-oceanic ridges:** A mid-oceanic ridge is composed of chains of mountains separated by a large depression. Oceanic ridge is also known as an **oceanic spreading center**, which is responsible for **seafloor spreading**. The uplifted sea floor results from *convection* currents which rise in the mantle as magma at a linear weakness in the oceanic crust, and emerge as lava, creating new crust upon cooling. A mid-ocean ridge demarcates the boundary between two tectonic plates, and consequently is termed a **divergent plate boundary**.
   The mountain ranges can have peaks as high as 2,500 m and some even reach above the ocean's surface. **Iceland**, a part of the mid-Atlantic Ridge, is an example.
2. **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.
3. **Submarine canyons:** These are deep valleys, found cutting across the continental shelves and slopes, extending from the mouths of large rivers. **The Hudson Canyon** is the best known submarine canyon in the world.

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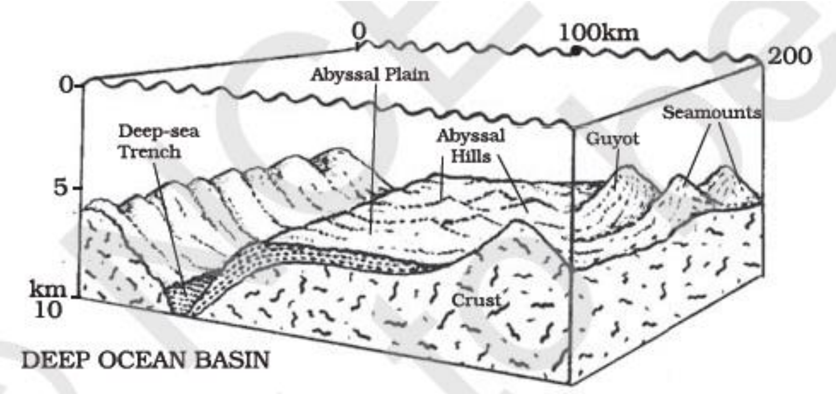
Figure 2. Minor Relief features of the ocean floor.



4. **Guyots:** It is a flat topped seamount. They show evidences of gradual subsidence through stages to become flat topped submerged mountains. It is estimated that more than 10,000 seamounts and guyots exist in the Pacific Ocean alone.
5. **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.

1.3. The Oceanic Deposits of the Ocean Floor

Materials eroded from the earth which are not deposited by rivers or at the coast are eventually dropped on the ocean floor. The dominant process is *slow sedimentation* where the eroded particles very slowly filter through the ocean water and settle upon one another in layers. All oceanic deposits can be classified as follows:

1. **Muds:** These are terrigenous deposits because they are derived from land and are mainly deposited on the continental shelves. The muds are referred to as blue, green or red muds; their colouring depends upon their chemical content.
2. **Oozes:** These are pelagic deposits because they are derived from the oceans. They are made of the shelly and skeletal remains of marine microorganisms with calcareous or siliceous parts. Oozes have a very fine, flour-like texture and either occur as accumulated deposits or float about in suspension.
3. **Clays:** These occur mainly as red clays in the deeper parts of the ocean basins, and are particularly abundant in the Pacific Ocean. *Red clay* is believed to be an accumulation of volcanic dust blown out from volcanoes during volcanic eruptions.

1.4. Temperature

Like land masses, ocean water varies in temperature from place to place both at the surface and at great depths. Ocean water gets heated by solar energy just as land. The process of heating and cooling of the oceanic water is *slower* than land. This is due to higher *specific heat* of water as compared to land as a result of which greater amount of energy is required to raise the temperature of water as compared to land.

1.4.1. Factors Affecting Temperature Distribution

The factors which affect the distribution of temperature of ocean water are:

1. **Latitude:** The temperature of surface water *decreases* from the equator towards the poles because the amount of **insolation** decreases poleward.
2. **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.

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3. **Prevailing winds:** The winds blowing from the land towards the oceans drive warm surface water away from the coast resulting in the *upwelling* of cold water from below. It results into the longitudinal variation in the temperature. Contrary to this, the onshore winds pile up warm water near the coast and this raises the temperature.
4. **Ocean currents:** Warm ocean currents raise the temperature in cold areas while the cold currents decrease the temperature in warm ocean areas.

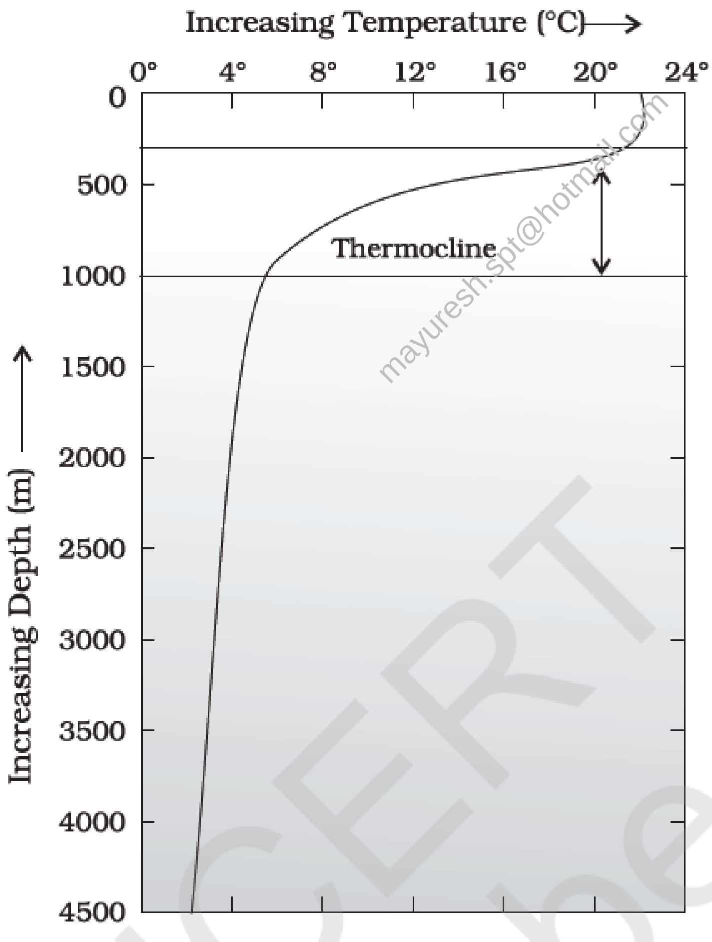
All these factors influence the temperature of the ocean currents locally. The *enclosed seas* in the low latitudes record relatively higher temperature than the open seas; whereas the enclosed seas in the high latitudes have lower temperature than the open seas.

1.4.2. Vertical Distribution of Temperature

It is a well-known fact that the maximum temperature of the oceans is always at their surfaces because they *directly receive the heat from the sun* and the heat is transmitted to the lower sections of the oceans through the process of **convection**. It results into decrease of temperature with the increasing depth, but the rate of decrease is not uniform throughout.

The temperature falls very rapidly up to the depth of 200 m and thereafter, the rate of decrease of temperature is slowed down. The temperature profile of oceans shows a boundary region between the surface waters of the ocean and the deeper layers. The boundary usually begins around 100-400m below the sea surface and extends several hundred of metres 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 thermoclinein the deep ocean. In this zone, temperatures approach 0°C.

Figure 3. Variation of temperature with depth in oceans



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The temperature structure of **oceans over middle and low latitudes** can be described asa three-layer system from surface to the bottom:

- The *first layer* represents the top layer of warm oceanic water and it is about 500m thick with temperatures ranging between 20° and25° C. This layer, within the tropical region, is present throughout the year but in mid-latitudes it develops only during summer.
- The *second layer* called the thermocline layer lies below the first layer and is characterized by rapid decrease in temperature with increasing depth. The thermocline is 500 -1,000 m thick.
- The *third layer* is very cold and extends up to the deep ocean floor. Here the temperatures are close to 0° C.

In the **Arctic and Antarctic circles**, surface water temperatures are close to 0° C and so the temperature change with the depth is very slight. Here, *only one layer of cold water exists*, which extends from surface to deep ocean floor.

1.4.3. Horizontal Distribution of Temperature

The average temperature of surface water of the oceans is about 27°C and it *gradually decreases from the equator towards the poles*. The rate of decrease of temperature with increasing latitude is generally *0.5°C per latitude*. The average temperature is around22°C at 20° latitudes, 14° C at 40° latitudes and 0° C near poles.

The oceans in the northern hemisphere record **relatively higher temperature** than in the southern hemisphere. The highest temperature is not recorded at the equator but slightly towards north of it. The average annual temperatures for the northern and southern hemisphere are around 19° C and 16°C respectively. This variation is due to the **unequal distribution of land and water** in the northern and southern hemispheres.

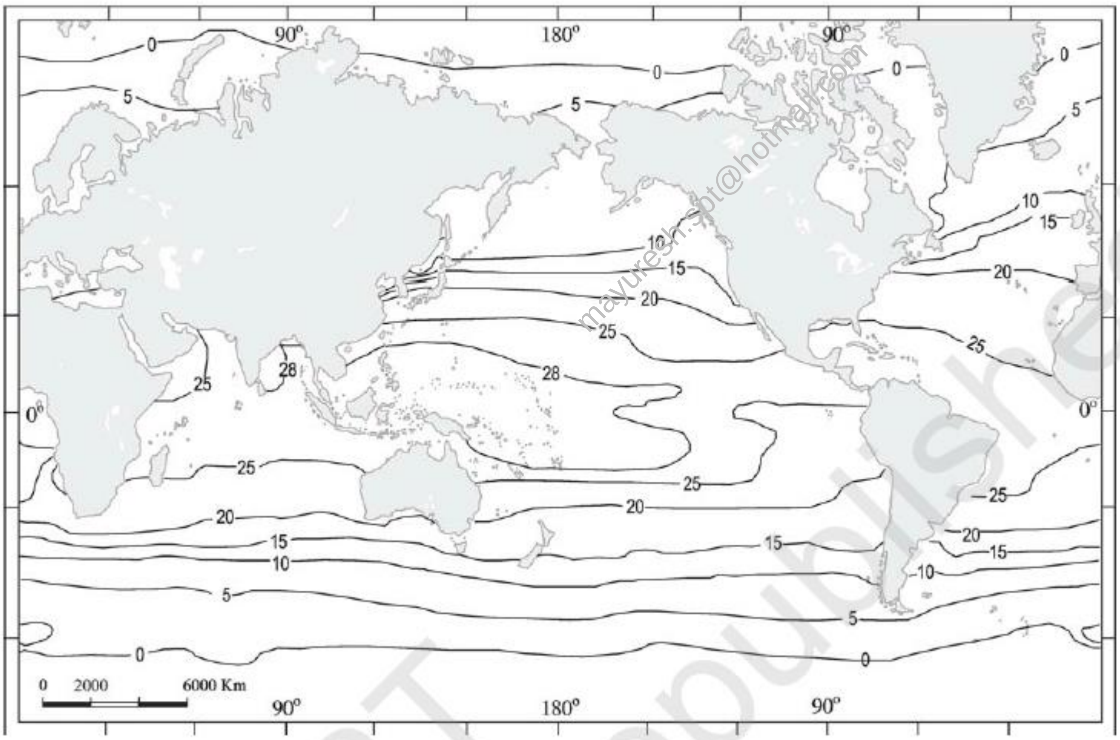

Figure 4. Horizontal Distribution of temperature of oceans around the world

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1.5. Salinity

Salinity is used to define the total content of *dissolved salts* in sea water. It is calculated as the amount of salt (in gm) dissolved in 1,000 gm (1 kg) of seawater. It is usually expressed as parts per thousand or ppt. Salinity is an important property of sea water. Salinity of 24.7 ppt has been considered as the upper limit to demarcate *brackish water*(saltier than fresh water, but not as salty as seawater).

1.5.1. Factors Affecting Ocean Salinity

Major factors are as mentioned below:

- The salinity of water in the surface layer of oceans depends mainly on *evaporation and precipitation.*
- Surface salinity is greatly influenced in coastal regions by the *fresh water* flow from rivers, and in polar-regions by the processes of freezing and thawing of ice.
- *Wind* also influences salinity of an area by transferring water to other areas.
- The *ocean currents* contribute to the salinity variations.

Salinity, temperature and density of water are *interrelated*. Hence, any change in the temperature or density influences the salinity of water in an area.

1.5.2. Vertical Distribution of Salinity

Salinity changes with depth but the way it changes depends upon the *location of the sea*. Salinity at the surface increases by *loss of water to ice or evaporation*, or decreases by the *input of fresh water*, such as from the rivers. Salinity at depth is very much fixed, because there is no way that water is lost, or the salt is added.

There is a marked difference in the salinity between the surface zones and the deep zones of the oceans. The lower salinity water rests above the higher salinity dense water. Salinity, generally, increases with depth and there is a distinct zone called the **halocline,** where salinity increases sharply. Other factors being constant, *increasing salinity of seawater causes its density to increase*. High salinity seawater, generally, sinks below the lower salinity water. This leads to **stratification by salinity**.

1.5.3. Horizontal Distribution of Salinity

The salinity for normal open ocean ranges between 33 ppt and 37 ppt. In the *land locked* **Red sea**, it is as high as 41 ppt, while in the estuaries and the **Arctic**, the salinity fluctuates from 0 – 35 ppt, seasonally. In hot and dry regions, where *evaporation is high*, the salinity sometimes reaches to 70 ppt.

The salinity variation in the **Pacific Ocean** is mainly due to its *shape* and *larger areal extent*. Salinity decreases from 35 ppt - 31 ppt on the western parts of the northern hemisphere because of the influx of *melted water from the Arctic region*. In the same way, after 15° - 20° south, it decreases to 33 ppt

The average salinity of the **Atlantic Ocean** is around 36 ppt. The highest salinity is recorded between 15° and 20° latitudes. Maximum salinity (37 ppt) is observed between20° N and 30° N and 20° W - 60° W. *It gradually decreases towards the north*. The **North Sea**, in spite of its location in higher latitudes, records higher salinity due to more saline water brought by the *North Atlantic Drift*. **Baltic Sea** records low salinity due to influx of river waters in large quantity. **The Mediterranean Sea** records higher salinity due to high evaporation. Salinity is, however, very low in **Black Sea** due to enormous fresh water influx by rivers.

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

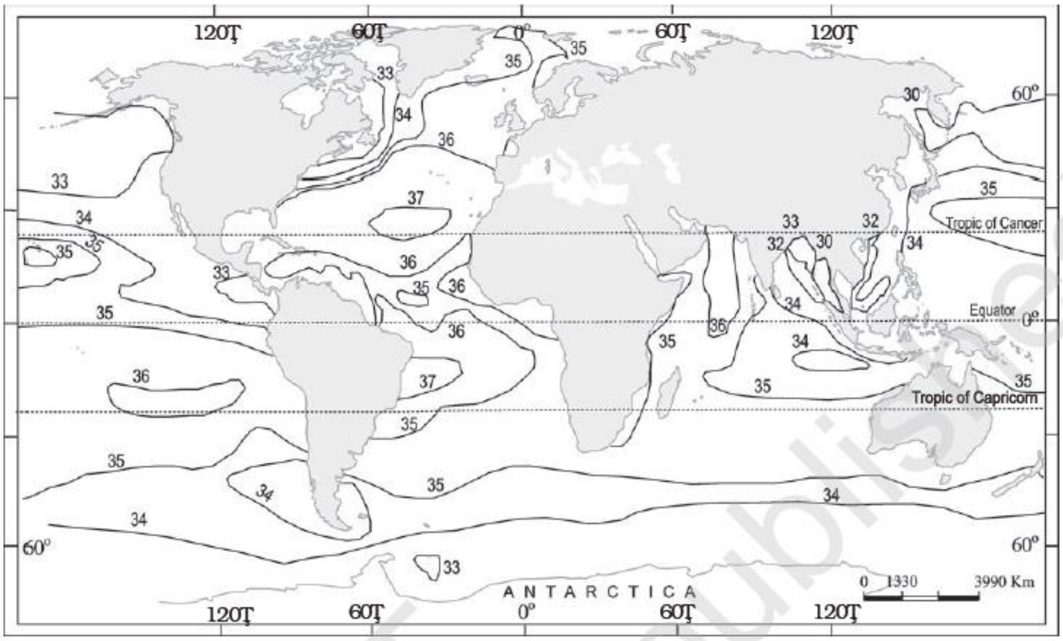


Figure 5. Surface salinity of World Oceans.

2. Movements of Ocean Water

Ocean water is dynamic. The horizontal motion refers to the *ocean currents* and *waves*. The vertical motion refers to *tides*. The *upwelling* of cold water from subsurface and the *sinking* of surface water are also forms of vertical motion of ocean water.

2.1. Waves

Waves are actually the **energy**, not the water as such, which moves across the ocean surface. Water particles only travel in a *small circle* as a wave passes. *Wind provides energy to the waves*. Wind causes waves to travel in the ocean and the energy is released on shorelines.

The motion of the surface water seldom affects the stagnant deep bottom water of the oceans. As a wave approaches the beach, it slows down. This is due to the **friction** occurring between the dynamic water and the sea floor and when the depth of water is less than half the wavelength of the wave, the wave breaks. *The largest waves are found in the open oceans*. Waves continue to grow larger as they move and absorb energy from the wind.

A wave's size and shape reveal its *origin*. **Steep waves** are fairly young ones and are probably formed by *local wind*. **Slow and steady waves** originate from faraway places, possibly from another hemisphere. The maximum wave height is determined by the strength of the wind, i.e. *how long it blows and the area over which it blows in a single direction*.

2.1.1. Characteristics of Waves

Important terms associated with waves are:

- *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 as they pass a fixed point.
- *Wavelength:* It is the horizontal distance between two successive crests.
- *Wave speed:* It is the rate at which the wave moves through the water, and is measured in knots.
- *Wave frequency:* It is the number of waves passing a given point during a one second time interval.

2.1.2. Wave Motion

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

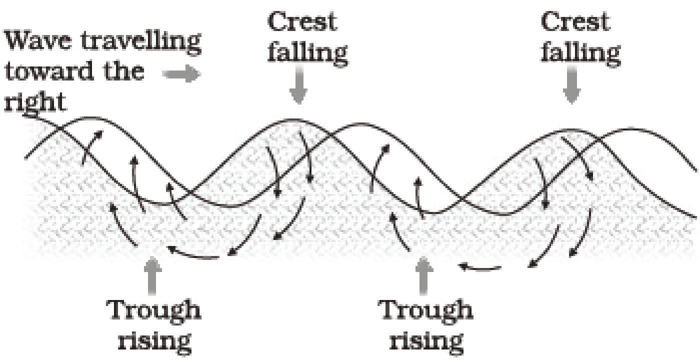


Figure 6. Motion of waves and water molecules

2.2. Tides

The *periodical* rise and fall of the sea level, once or twice a day, mainly due to the attraction of sun and the moon, is called a *tide*. Movement of water caused by meteorological effects (winds and atmospheric pressure changes) are called *surges*. Surges are not regular like tides. The study of tides is very complex, spatially and temporally, as it has great variations in frequency, magnitude and height.

2.2.1. Causes of Tides

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 is the force that acts to counterbalance the gravity. Together, the gravitational pull and the centrifugal force are responsible for creating the *two major tidal bulges* on the earth.

Student Notes:

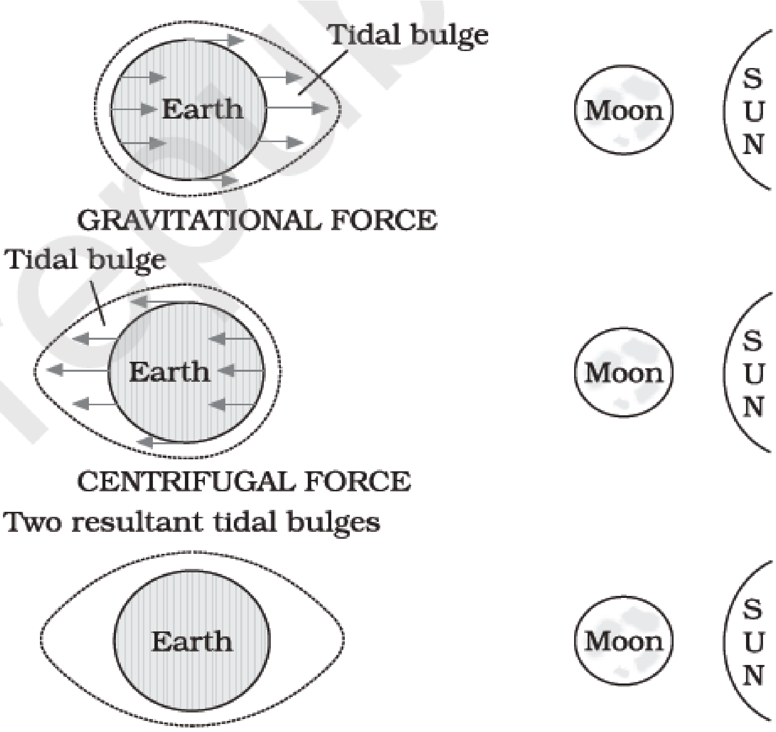


Figure 7. Relation between gravitational forces and centrifugal forces

The 'tide-generating' force is the *difference between the gravitational attraction of the moon and the centrifugal force*. On the surface of the earth, nearest the moon, pull or the attractive force of the moon is greater than the centrifugal force, and so there is a net force causing a bulge towards the moon.

On the opposite side of the earth, the attractive force is less, as it is farther away from the moon, the centrifugal force is dominant. Hence, there is a net force away from the moon. It creates the second bulge away from the moon.

2.2.2. 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 based on their *height*.

2.2.3. Tides Based on Rrequency

1. ***Semi-diurnal tide:*** The most common tidal pattern, featuring two high tides and two low tides each day. The successive high or low tides are approximately of the same height.
2. ***Diurnal tide:*** There is only one high tide and one low tide during each day. The successive high or low tides are approximately of the same height.
3. ***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.

2.2.4. Tides Based on Height

The height of rising water (high tide) varies appreciably depending upon the *position of sun and moon with respect to the earth*:

1. **Spring tides:** On *full moon* and *new moon* days, the Sun, the Moon and the Earth are almost in the *same line*. On these days, the Sun and the Moon exert their *combined gravitational force* on the Earth. Thus on these two days the high tides are the *highest* and are known as

spring tides. The height of a spring tide is about 20 per cent more than the normal high tide. They occur twice every month.

2. **Neap tides:** On *half Moon* days (i.e. first and last quarter phases of the Moon), the Sun and the Moon are at *right angles* to the centre of the Earth. The tide producing forces of the Moon and the Sun, work in *opposite directions* and they partly cancel each other's force. In such cases, the high tide is lower than the normal and low tide is higher than the normal. The difference is about 20 per cent. This is known as the neap tide.

2.2.5. Characteristics of Tides

- **Tidal range:** The difference between the high tide water and the low tide water is called the tidal range. 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**.

  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 gravitation force is limited and the tidal ranges are less than their average heights.

  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.

- **Tidal current:** Tidal currents (a horizontal motion) are a result of the rise and fall of the water level due to tides (a vertical motion). The effects of tidal currents on the movement of water in and out of bays and harbours can be substantial.
  The tidal bulges on *wide continental shelves*, have greater height. When tidal bulge shit the mid-oceanic islands they become low. The shape of bays and estuaries along a coastline can also magnify the intensity of tides. *Funnel-shaped bays* greatly change tidal magnitudes. The highest tides in the world occur in the **Bay of Fundy in Nova Scotia, Canada**. The tidal bulge is 15 - 16 m.
- **Tidal bore:** When the tide enters the narrow and shallow estuary of a river, the front of the tidal wave appears to be vertical due to the piling up of the river water against the tidal wave and the friction of the river bed. It looks as if a vertical wall of water is moving upstream. This is called a tidal bore. In India tidal bores are common in the *Hugli River*.

2.2.6. 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. Some of the important activities associated with tides are:

1. Tidal flows are of great importance in **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. Large ships enter the harbour of a shallow sea during high tide and they go back also at the time of high tide. *London* and I have become important ports due to the tidal nature of the mouths of the *Thames* and *Hugli* rivers respectively.
2. The river mouths and estuaries are kept **clean of sedimentation** due to the action of tidal currents. The force of the outgoing tide and the river current carries the silt away to the open sea. This helps in navigation.
3. The tidal force can also be used as a source for **generating electricity**. A 3 MW tidal power project at *Durgaduani* in *Sunderbans* of West Bengal is under way.

Student Notes:

4. The inflow of the salty tidal water, especially along the coast of cold countries, retards the process of freezing and *prevents the harbours from becoming ice-bound*.
5. The fishing industry is helped by the rhythm of high and low tides. The fishermen mostly sail out to the open sea during low tides and return to the coast at high tides.

2.3. Ocean Currents

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

2.3.1. Causes of Ocean Currents

Ocean currents are influenced by two types of forces namely:

- **Primary forces** that initiate the movement of water.
- **Secondary forces** that influence the currents to flow.

The forces that influence the currents are:

1. **Heating by solar energy** causes water to *expand*. That is why, near the equator the ocean water is about 8 cm higher in level than in the middle latitudes. This causes a very *slight gradient* and water tends to flow down the slope.
   There is much difference in the temperature of ocean waters at the equator and at the poles. As *warm water is lighter and rises*, and *cold water is denser and sinks*, warm equatorial waters move slowly along the surface polewards, while the heavier cold waters of the polar regions creep slowly along the bottom of the sea equatorwards.
2. **Wind** blowing on the surface of the ocean pushes the water to move. *Friction* between the wind and the water surface affects the movement of the water body in its course. Most of the ocean currents of the world follow the direction of the prevailing winds.
3. **Coriolis force** causes the water to move to the *right in the northern hemisphere* and to the *left in the southern hemisphere*. These large accumulations of water and the flow around them are called **Gyres.** These produce large circular currents in all the ocean basins.
4. **Salinity** of ocean water varies from place to place. Waters of high salinity are denser than waters of low salinity. Hence on the surface, waters of low salinity flow towards waters of high salinity while at the bottom, waters of high salinity flow towards waters of low salinity.
5. The **configuration of the coastline** serves as an obstruction for the natural flow of ocean currents and succeeds in changing its direction. This is quite conspicuous in the equatorial region where the landmasses deflect the current towards the north and the south.

2.3.2. Types of Ocean Currents

The ocean currents may be classified based on their *depth* or *temperature*.

2.3.3. Currents Based on Depth

1. **Surface currents** constitute about10 per cent of all the water in the ocean, these waters are the upper 400 m of the ocean.
2. **Deep water currents** make up the other 90 per cent of the ocean water. Deep waters sink into the deep ocean basins at high latitudes, where the temperatures are cold enough to cause the density to increase.

2.3.4. Currents Based on Temperature

1. **Cold currents** bring coldwater into warm water areas. These currents are usually found on the *west coast of the continents in the low and middle latitudes* (true in both hemispheres) and on the *east coast in the higher latitudes in the Northern Hemisphere*.

Student Notes:

2. **Warm currents** bring warm water into cold water areas and are usually observed on the east coast of continents in the low and middle latitudes (true in both hemispheres). In the northern hemisphere they are found on the west coasts of continents in high latitudes.

2.3.5. Characteristics of Ocean Currents

The currents are *strongest near the surface* and may attain speeds over five knots. At depths, currents are generally slow with speeds less than 0.5knots. The speed of a current is known as its **drift**. Drift is measured in terms of knots. The **strength of a current** refers to the speed of the current. *A fast current is considered strong*. A current is usually strongest at the surface and decreases in strength (speed) with depth. Most currents have speeds less than or equal to 5 knots.

2.3.6. Currents of the Atlantic Ocean

Major currents of the Atlantic Ocean are:

North and South Equatorial Current

- To the north and south of the equator, there are two westward moving currents-the North Equatorial Current and the South Equatorial Current.
- Due to the rotation of the Earth (Coriolis Effect), these currents move almost due west along the equator.
- The North Equatorial Current moves northwards due to the presence of the South American continent and the Coriolis force, and takes the north-west direction. It enters *the Gulf of Mexico* to form the **Gulf Stream**.
- The **South Equatorial Current** originates from the western coast of Africa, from where it moves towards South America.
- The east coast of Brazil obstructs the South Equatorial Current which then bifurcates into two branches.
- The northward branch merges with the North
- Equatorial Current, while the second branch flows along the east coast of Brazil and is known as the Brazilian Current.
- The North Equatorial Current and the South Equatorial Current are warm currents.

Gulf Stream

- The Gulf Stream is one of the largest warm currents. It originates from the Gulf of Mexico (about 20° N) and moves in a north-easterly direction along the eastern coast of North America.
- The average speed is about 33 km per day and its average width is about 70 km.
- Under the impact of the Westerlies, this warm current reaches the western coast of Europe (about 70° N latitude).
- The general direction of flow of the Gulf Stream, north of 30° N latitude, is northward.
- Near Newfoundland, its water mixes with the cold water of the Labrador Current, which forms very dense fog. The foggy conditions around Newfoundland hamper the navigation of ships.
- From here, the Gulf Stream moves northeastwards.
- This current gradually widens and its speed decreases. It becomes a prominent, slow-moving current known as the North Atlantic Drift.
- Near Western Europe, it splits into two parts. One part moves northwards, past UK and Norway, while the other part is deflected southwards as the cold Canary Current.
- The warm water of the Gulf Stream modifies the weather conditions off the eastern coast of North America and the western coast of Europe.

Student Notes:

- On the western coast of Europe, the seaports remain open even in the severe winter season due to the warm water of the Gulf Stream.

Labrador Current

- The cold Labrador Current of the North Atlantic Ocean, has its origin in the Arctic Ocean.
- This current flows from north to south between Greenland and the Baffin islands.
- The Labrador Current merges with the Gulf Stream near Newfoundland.
- This helps in the growth of plankton- a feed for fish. Thus the Grand Banks near Newfoundland have become the ideal fishing ground in the world.
- The average speed of the Labrador Current is about 25 km per day.
- This current brings huge icebergs with it from the Arctic Ocean.

Canary Current

- The Canary Current is a cold current and flows along the western coast of Spain and Portugal and the north-west coast of North Africa. .
- The average speed of this current is about 45 km per day.
- The relative coolness of the Canary Current reduces the relative humidity and thus causes scanty rainfall in the greater parts of the Sahara Desert.

Brazil Current

- The Brazil Current is a warm current and flows southward along the east coast of South America (about 40° S latitude).
- The average speed of the Brazil Current is about 30 km per day.
- From 40° S, it is deflected eastwards due to the Earth's rotation and flows in easterly direction.
- It modifies the weather conditions along the eastern coasts of Brazil and Argentina.

Falkland Current

- The cold waters of the Antarctic Sea flow as Falkland Current from south to north along the eastern coast of South America up to Argentina.
- The Falkland Current brings huge icebergs from the Antarctic region to the South American coast.

Benguela Current

- The Benguela Current is a cold current which originates in the Antarctic region and flows along the coast of south-west Africa.
- The Benguela Current helps in reducing the relative humidity of the eastward moving warm and moist air masses.
- The Kalahari Desert is largely formed under the influence of this current.
- Further northwards, the Benguela Current merges with the South Equatorial Current.

South Atlantic Drift

- The eastward continuation of the Brazil Current is called the South Atlantic Drift or the West Wind Drift.
- It develops at about 40° S latitude due to the impact of the Westerlies.
- The eastward movement is due to the Earth's rotation.

Student Notes:

2.3.7. Currents of the Pacific Ocean

Major currents of the Pacific Ocean are:

North Equatorial Current

- The North Equatorial Current is a warm current which originates off the western coast of Mexico and flows in the westerly direction.
- It runs parallel to the equator and reaches the islands of Philippines after covering a distance of about 12,000 km.
- Near Philippines, under the impact of Coriolis force, it turns northwards.
- One branch of the North Equatorial Current flows northward to join the Kuroshio Current, while the southern branch turns eastwards to form the Counter Equatorial Current.

South Equatorial Current

- The South Equatorial Current is a warm current which originates due to the influence of South-east Trade winds and flows from east to west.
- It bifurcates into northern and southern branches near New Guinea.
- The northern branch turns eastward and joins the Counter Equatorial Current, while the southern branch flows along the north-eastern coast of Australia.

Kuroshio Current

- Kuroshio Current is an important warm current, which develops partly due to the Coriolis force and partly due to the obstruction by the Philippines in the flow of the North Equatorial Current.
- The average velocity is about 30 km per day and the average surface temperature is about 20°C.
- This current keeps the eastern coast of Japan warm even in the coldest month (January), when it is snowing heavily in Honshu and Hokkaido.
- A branch of Kuroshio Current enters the Sea of Japan as Tsushima Current and keeps the western coast of Japan comparatively warm.
- Around 35° N, the Kuroshio current comes under the impact of the Westerlies and flows in the north-east direction to reach the western coast of North America.
- Further northwards, it is known as the Aleutian Current.

Kurile or Oyashio Current

- The Kurile or Oyashio Current is a cold current which originates from the Bering Strait and moves southwards along the coast of the Kamchatka peninsula to touch the island of Kurile.
- It carries with it the cold water and icebergs from the Arctic Ocean to the coast of eastern Russia and Japan.
- Near 50° N latitude, it is bifurcated into two branches. One of them merges with Kuroshio Current and creates dense fog which is hazardous to navigation, but ideal for abundant growth of plankton.
- Thus the north-eastern coast of the Japanese islands is an important fishing ground in the world.
- The second branch moves up to the Japanese coast.
- The Oyashio Current is comparable to the Labrador Current of the North Atlantic Ocean.

California Current

- The California Currents is a cold current which flows southwards along the Pacific coastline of USA, and is comparable to the Canary Current of the Atlantic Ocean in most of its characteristics.

- After reaching the Mexican coast, it turns westward and merges with the North Equatorial Current.
- Dense sea fogs are experienced off the coast of San Francisco.

Peru Current

- The Peru Current is a cold current, also known as the Humboldt Current, which flows along the western coast of South America.
- It flows from south to north along the coast of Peru and is caused by the northward deflection of the West Wind Drift.
- It affects the coastal climate of Chile and Peru.

East Australian Current

- The East Australian Current is a warm current which is the southern branch of the South Equatorial Current, which flows from north to south along the eastern coast of Australia.
- New Zealand is surrounded by this current.
- It raises the temperature along the east Australian and the New Zealand coasts for considerable distance southwards.

West Wind Drift

- It is a strong, cold current, flowing from between Tasmania and South American coast.
- It flows under the influence of the Westerlies and is largely confined between 40° Sand 50° S latitudes.
- This current becomes very strong due to large volume of water and high velocity winds (Roaring Forties).
- One of its branch enters the Atlantic Ocean through Cape Hom, and the other branch turns northwards and joins the Peru Current.

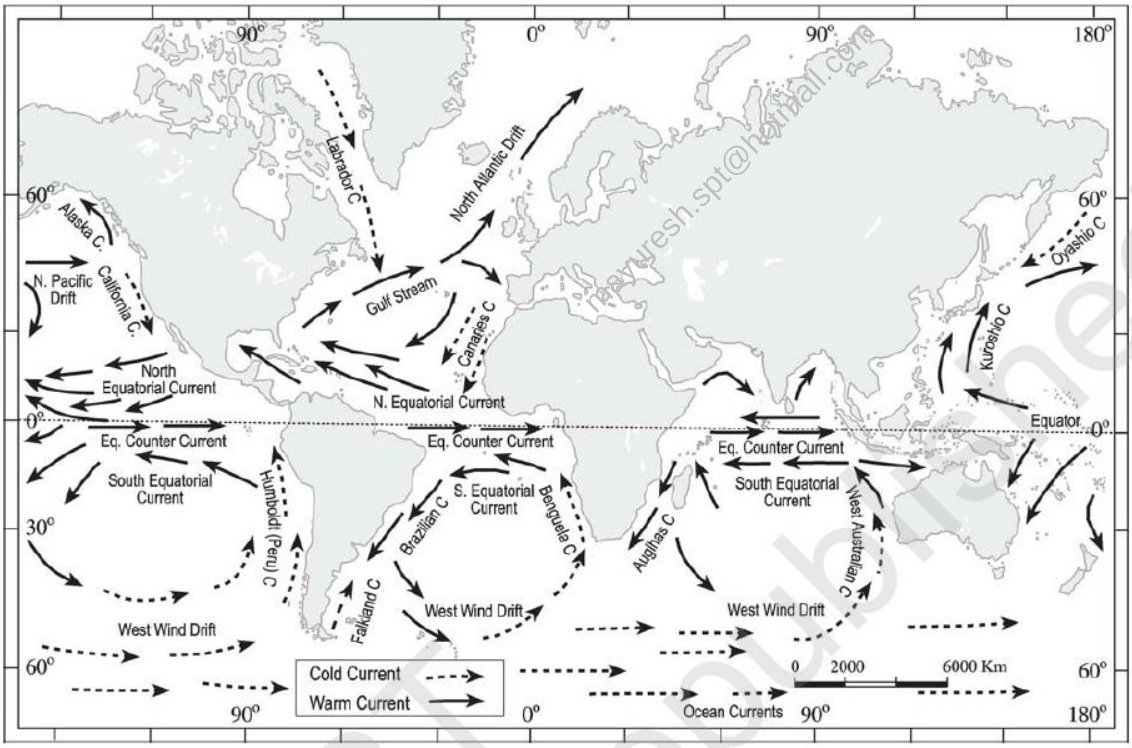


Figure 8. Major Ocean currents

Student Notes:

2.3.8. Currents of the Indian Ocean

The ocean currents of the Indian Ocean are largely controlled and modified by the landmasses and the Monsoon winds. The ocean currents of the **North Indian Ocean** flow under the influence of the north-east and the south-west Monsoon winds. Thus the ocean currents change the direction of flow twice a year.

The currents in the **southern Indian Ocean** follow the general pattern of other oceans and are not affected by the seasonal changes in the direction of Monsoon winds.

Major currents of the Indian Ocean are:

North-east Monsoon Current

- In the winter season, the north-east Monsoon winds blow from land to ocean and from the northeast to the south-west in the Northern Hemisphere.
- Under the influence of these winds, the ocean current also flows from the north-east to the southwest.

South-west Monsoon Current

- There is a complete reversat in the direction of Monsoon winds during the summer season and they blow from the south-west to the north-east in the Northern Hemisphere.
- This also reverses the direction of the ocean current. Now the direction of the ocean current also changes from the south-west to the northeast.
- Two branches of the main current move in the Arabian Sea and the Bay of Bengal.

South Equatorial Current

- The warm South Equatorial Current flows from east to west between 10° Sand 15° S latitudes from the western coast of Australia to the coast of Africa.
- After being obstructed by the Madagascar Island, this current is divided into many branches.
- One major branch flows towards the south as the Agulhas Current.

Agulhas Current

- The Agulhas Current is a warm current which is a branch of the South Equatorial Current which flows along the eastern coast of Madagascar.
- It continues southwards up to about 30° S, where it merges with the Mozambique Current.
- Around 35° S latitude, it comes under the influence of the Westerlies and flows towards the east.

Mozambique Current

- The Mozambique Current is a warm current which is the northern branch of the South Equatorial Current which enters the Mozambique Channel around 10° S latitude.
- Moving southwards between Mozambique and Madagascar, it joins the Agulhas Current around 30°S latitude.

West Wind Drift

- The West Australian Current is a cold current is in the southern part of the Indian Ocean and moves from west to east around 40° S latitude.
- The West Wind Drift develops under the influence of the Westerlies (Roaring Forties).

Student Notes:

West Australian Current

- The West Australian Current is a cold current which flows along the western coast of Australia.
- This current turns towards west and north-west near the Tropic of Capricorn and finally merges with the South Equatorial Current.
- The second branch flows to the south of Australia and finally merges with the West Wind Drift in the Pacific Ocean.

2.3.9. Effects of Ocean Currents

- The oceanic circulation *transports heat from one latitude belt to another* in a manner similar to the heat transported by the general circulation of the atmosphere. The cold waters of the Arctic and Antarctic circles move towards warmer water in tropical and equatorial regions, while the warm waters of the lower latitudes move polewards.
- *West coasts* of the continents in *tropical and subtropical latitudes* (except close to the equator) are bordered by *cool waters*. Their average temperatures are relatively low with narrow diurnal and annual ranges. There is fog, but generally the areas are arid.
- *West coasts* of the continents in the *middle and higher latitudes* are bordered by *warm waters* which cause a *distinct marine climate*. They are characterised by cool summers and relatively mild winters with a narrow annual range of temperatures.
- *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.
- The *mixing of warm and cold currents* help 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.**

3. Ocean Resources

The ocean is one of Earth's most valuable natural resources. It provides food in the form of fish and shellfish. It's used for transportation—both travel and shipping. It provides a treasured source of recreation for humans. It is mined for minerals and drilled for crude oil. We discuss all these in greater detail below:

3.1. Fishing

The oceans have been fished for thousands of years and are an integral part of human society. Fish have been important to the world economy for all of these years. Fisheries of today provide about 16% of the total world's protein with *higher percentages occurring in developing nations*. Marine fisheries are very important to the economy and well-being of coastal communities, providing food security, job opportunities, income and livelihoods as well as traditional cultural identity.

The word fisheries refers to all of the fishing activities in the ocean, whether they are to obtain fish for the commercial fishing industry, for recreation or to obtain ornamental fish or fish oil. Fishing activities resulting in fish not used for consumption are called **industrial fisheries**. Due to the relative abundance of fish on the continental shelf, fisheries are usually marine and not freshwater.

3.1.1. Major Fishing Grounds

The major commercial fishing grounds are located in the cool waters of the *northern hemisphere in comparatively high latitudes*. Commercial fishing is *little developed in the tropics or in the southern hemisphere*. The best fishing grounds are found above continental shelves which are not more than 200 metres below the water surface, where plankton of all kinds are most abundant.

The world's most extensive continental shelves are located in high or mid-latitudes in the northern hemisphere, e.g., **the banks of Newfoundland**, **the North Sea** and **the continental shelf off north-western Europe**, and **the Sea of Japan**.

Plankton are in plentiful supply in polar waters, at *the meeting of cold and warm ocean currents as on the Newfoundland 'banks' and the Sea of Japan, or where cold water from the ocean floor wells up to the surface as it does off the west coast of South America*. The continental shelves of the tropics are relatively less rich in plankton because the water is warm.

The amount of fish available in the oceans is an ever-changing number due to the effects of both natural causes and human developments. It will be necessary to manage ocean fisheries in the coming years to make sure the number of fish caught never makes it to zero.

3.2. Climate Buffer

Water has a very high specific heat capacity. This means that a lot of energy is needed to increase its temperature (energy is needed to overcome the hydrogen bonds). As the Earth is 71% water, energy from the sun causes only small changes in the planet's temperature. This stops the Earth getting too hot or too cold and makes conditions possible for life. *Heat is stored by the ocean in summer and released back to the atmosphere in winter.* Oceans, therefore, *moderate climate by reducing the temperature differences between seasons.*

By far the largest carbon store on Earth is in sediments, both on land and in the oceans, and it is held mainly as calcium carbonate. The second biggest store is the deep ocean where carbon occurs mostly as dissolved carbonate and hydrogen carbonate ions. *About a third of the carbon dioxide from fossil fuel burning is stored in the oceans and it enters by both physical and biological processes.*

3.3. Phytoplankton

Phytoplankton accounts for around 90% of the world's oxygen production because water covers about 70% of the Earth and phytoplankton are abundant in the photic zone of the surface layers. Some of the oxygen produced by phytoplankton is absorbed by the ocean, but most flows into the atmosphere where it becomes available for oxygen dependent life forms.

3.4. Mining

The oceans hold a veritable treasure trove of valuable resources. **Sand and gravel**, **oil** and **gas** have been extracted from the sea for many years. In addition, minerals transported by erosion from the continents to the coastal areas are mined from the shallow shelf and beach areas. These include *diamonds off the coasts of South Africa and Namibia* as well as deposits of *tin, titanium* and *gold* along the shores of *Africa, Asia and South America*.

Natural gas and oil have been extracted from the seas for decades, but the ores and mineral deposits on the sea floor have attracted little interest. Yet as resource prices rise, so too does the appeal of ocean mining.

3.4.1. Deep Sea Mining

Back in the early 1980s there was great commercial interest in marine mining. This initial euphoria over marine mining led to the **International Seabed Authority** (ISA) being established in Jamaica, and the **United Nations Convention on the Law of the Sea** (UNCLOS) being signed in 1982 – the "constitution for the seas". Since entering into force in 1994, this major convention has formed the basis for signatories' legal rights to use the marine resources on the sea floor outside national territorial waters.

After that, however, the industrial countries lost interest in resources. For one thing, prices dropped making it no longer profitable to retrieve the accretions from the deep sea and utilize the metals they contained. Also, new onshore deposits were discovered, which were cheaper to exploit.

The **present resurgence of interest** is due to:

- The sharp increase in resource prices and attendant rise in profitability of the exploration business.
- Strong economic growth in countries like China and India which purchase large quantities of metal on world markets. Even the latest economic crisis is not expected to slow this trend for long.
- The industrial and emerging countries' geopolitical interests in safeguarding their supplies of resources also play a role. In light of the increasing demand for resources, those countries which have no reserves of their own are seeking to assert extraterritorial claims in the oceans.

3.4.2. Major Deep Sea Minerals

The major focus is on **manganese nodules**, which are usually located at depths below 4000 metres, **gas hydrates** (located between 350 and 5000 metres), and **cobalt crusts** along the flanks of undersea mountain ranges (between 1000 and 3000 metres), as well as **massive sulphides** and the **sulphide muds** that form in areas of volcanic activity near the plate boundaries, at depths of 500 to 4000 metres.

Manganese Nodules

Manganese nodules are lumps of minerals covering huge areas of the deep sea with masses of up to 75 kilograms per square metre. Manganese nodules are composed primarily of manganese and iron. *The elements of economic interest, including cobalt, copper and nickel, are present in lower concentrations and make up a total of around 3.0 per cent by weight.* In addition there are traces of other significant elements such as *platinum* or *tellurium* that are important in industry for various high-tech products.

These chemical elements are *precipitated from seawater or originate in the pore waters of the underlying sediments*. The greatest densities of nodules occur off the **west coast of Mexico**, in the **Peru Basin**, and the **Indian Ocean**.

Cobalt crusts

These crusts accumulate when manganese, iron and a wide array of trace metals dissolved in the water (cobalt, copper, nickel, and platinum) are deposited on the volcanic substrates. The cobalt crusts also contain relatively small amounts of the economically important resources. Extracting cobalt from the ocean is of particular interest because it is found on land in only a few countries (Congo, Zaire, Russia, Australia and China), some of which are politically unstable.

Cobalt crusts form at depths of 1000 to 3000 metres on the flanks of *submarine volcanoes*, and therefore usually occur in regions with high volcanic activity such as the territorial waters around the island states of the South Pacific.

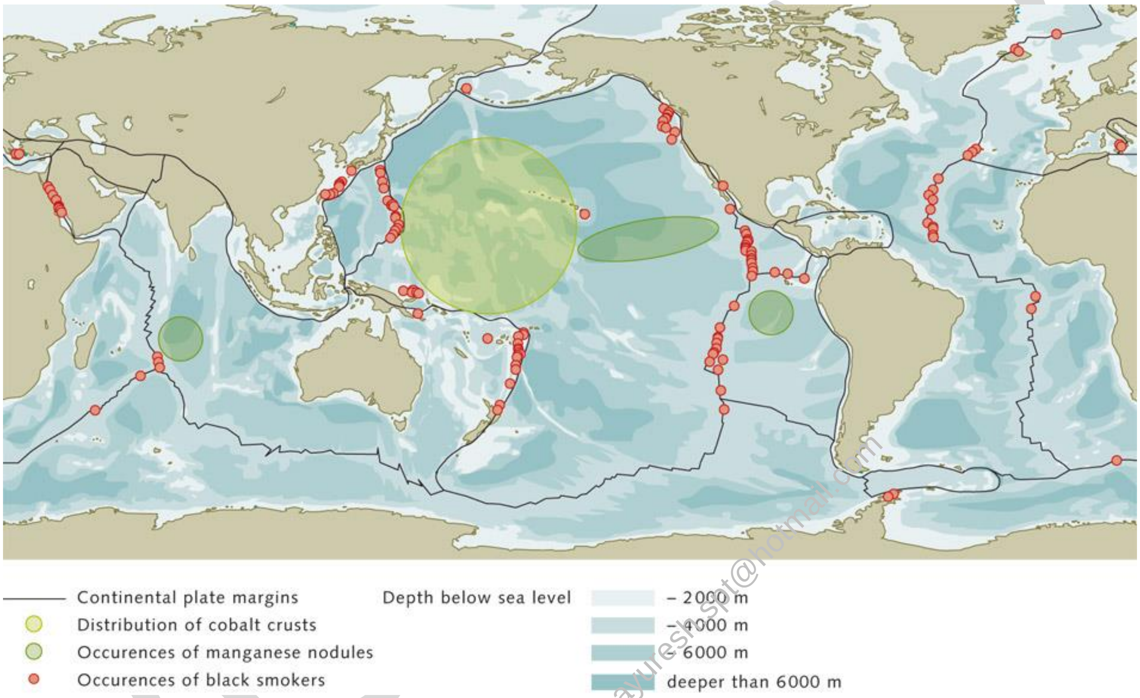
Massive Sulphides

Sulphur deposits produced from **underwater volcanic areas** are known as black smokers. These occurrences of massive sulphides form at *submarine plate boundaries*, where an exchange of heat and elements occurs between rocks in the Earth's crust and the ocean due to the interaction of volcanic activity with seawater.

Cold seawater penetrates through cracks in the sea floor down to depths of several kilometres. Near heat sources such as magma chambers, the seawater is heated to temperatures exceeding 400 degrees Celsius. Upon warming, the water rises rapidly again and is extruded back into the sea. These hydrothermal solutions transport metals dissolved from the rocks and magma, which are then deposited on the sea floor and accumulate in layers. This is how the massive sulphides and **the characteristic chimneys** (black smokers) are produced.

So far only a few massive sulphide occurrences which are of economic interest due to their size and composition are known. While the black smokers along the **East Pacific Rise** and in the **central Atlantic** produce sulphides comprising predominantly ironrich sulphur compounds – which are not worth considering for deep-sea mining – the occurrences in the **southwest Pacific** contain greater amounts of copper, zinc and gold. The *largest known sulphide occurrence* is located in the **Red Sea** Here, the sulphides are not associated with black smokers, but appear in the form of iron rich ore muds.

Figure 9. Distribution of Deep Sea Minerals



3.4.3. Constraints in Deep Sea mining

Major problems associated with deep sea mining are:

- The most limiting factors associated with deep-sea marine mining are the political and legal aspects. Legal and political issues surrounding exploration, exploitation, and marketing of sea floor minerals must be resolved.
- The excavation of marine minerals would considerably disturb parts of the seabed. Huge amounts of sediment, water, and countless organisms would be dug up with the nodules, and the destruction of the deep-sea habitat would be substantial. It is not yet known how, or even whether, repopulation of the excavated areas would occur.
- Sea floor mining will only be able to compete with the substantial deposits presently available on land if there is sufficient demand and metal prices are correspondingly high.
- The excavation technology has yet to be developed. There are serious technological difficulties in separating the crusts from the substrate which combined with the problems presented by the uneven sea floor surface further reduce the economic potential of the marine mining.

Despite the challenges, deep sea mining has some **potential benefits over terrestrial mining**:

- The minerals are often much closer to the surface, so operations have to dig and displace less rock, meaning a smaller footprint and fewer carbon emissions.
- Seabed mining infrastructure is both moveable and reusable, unlike roads and buildings often left behind at abandoned mines on land.
- And no residents will be directly displaced by mining.

4. UPSC Questions Related to Above Topics

1. 'Temperature, salinity and density differences in ocean water are the prime causes of ocean water circulation.' Elaborate. (Geography Mains – 2011, 30 marks)
2. Write short notes on ocean deposits. (Geography Mains – 2010, 15 marks)
3. Write short notes on Ocean Currents of the North Atlantic Ocean.(Geography Mains- 2007, 200 words)
4. Present a concise account of bottom relief of the Indian Ocean. (Geography Mains 2003)
5. Give a reasoned account of the distribution of salinity in the oceans and partially enclosed seas. (Geography Mains 1994)
6. Discuss the features of Gulf Stream. (IFoS-2011)
7. The major fishing grounds of the world are located in areas where cool and warm currents converge. Discuss. (IFoS-2011)
8. Give an account of oceanic mineral resources. (IFoS-2010)
9. List the processes that initiate ocean currents and influence their speed and direction. (IFoS-2009)
10. Distinguish between continental crust and continental rise. (IFoS – 2009)
11. What are ocean currents? State the uses of ocean currents. (IFoS – 2005)

Student Notes:

CORAL REEFS AND INDIAN OCEAN

Contents

Student Notes:

1. Coral Reefs

Coral reefs are some of the *most diverse ecosystems* in the world. Thousands of species rely on reefs for survival. Thousands of communities all over the world also depend on coral reefs for food, protection and jobs.

A **reef** is a strip or ridge of rocks, sand, or coral that rises to or near the surface of a body of water. The best-known reefs are the coral reefs developed through biotic processes dominated by **corals** and calcareous algae.

1.1. Corals

Corals are **animals**, even though they may exhibit some of the characteristics of plants and are often mistaken for rocks. Corals can exist as individual polyps (a small sea animal that has a body shaped like a tube), or in colonies and communities that contain hundreds to hundreds of thousands of polyps. Corals are found throughout the oceans, from deep, cold waters to shallow, tropical waters.

1.1.1. Types of Corals

Corals are classified as under:

1. **Hard Corals:** Hard corals, also known as *stony corals*, produce a rigid skeleton made of *calcium carbonate* in crystal form called aragonite**.** Hard corals are the primary **reef-building** corals. Hard corals consisting of hundreds to hundreds of thousands of individual polyps are cemented together by the **calcium carbonate** 'skeletons' they secrete. Living coral grow on top of the skeletons of their dead predecessors. Hard corals that form reefs are called **hermatypiccoral**.
2. **Soft Corals:** Soft coral, also known **ahermatypic coral**, do not produce a rigid calcium carbonate skeleton and do not form reefs, though they may be present in a reef ecosystem. Soft corals are also mostly colonial i.e. what appears to be a single large organism is actually a colony of individual polyps combined to form a larger structure. Soft coral colonies tend to resemble trees, bushes, fans, whips, and grasses.

1.2. Zooxanthellae

Most reef-building corals contain **photosynthetic algae**, called zooxanthellae, that live in their tissues. *The corals and algae have a mutualistic relationship*. The coral provides the algae with a protected environment and compounds they need for photosynthesis. In return, the algae produce oxygen and help the coral to remove wastes.

Zooxanthellae supply the coral with glucose, glycerol, and amino acids, which are the products of photosynthesis. The coral uses these products to make proteins, fats, and carbohydrates, and produce **calcium carbonate**. This is the driving force behind the growth and productivity of coral reefs.

In addition to providing corals with essential nutrients, zooxanthellae are responsible for the *unique and beautiful colors of many stony corals*. Sometimes when corals become physically stressed, the polyps expel their algal cells and the colony takes on a *stark white appearance*. This is commonly described as **coral bleaching**. If the polyps go for too long without zooxanthellae, *coral bleaching can result in the coral's death*.

1.3. Coral Formation and Types

Coral reefs begin to form when free-swimming coral larvae attach to submerged rocks or other hard surfaces along the edges of islands or continents. As the corals grow and expand, reefs take on one of three major characteristic structures:

- **Fringing reefs**, which are the most common, project seaward directly from the shore, forming borders along the shoreline and surrounding islands.
- **Barrier reefs** also border shorelines, but at a greater distance. They are separated from their adjacent land mass by a lagoon of open, often deep water.
- An **atoll** forms if a fringing reef forms around a *volcanic island* that subsides completely below sea level while the coral continues to grow upward. Atolls are usually circular or oval, with a central **lagoon**.

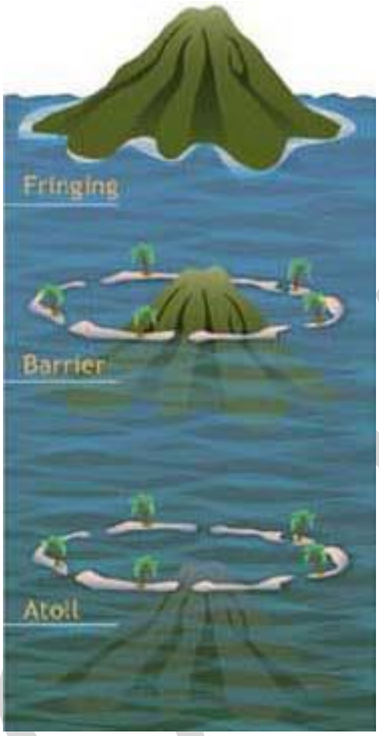


Figure 1. Types of Coral Reefs

2. Conditions Needed for Growth of Coral Reefs

Corals are found throughout the oceans, from deep, cold waters to shallow, tropical waters. Conditions favourable to growth of corals reefs can be discussed as under:

1. Shallow coral reefs grow best in **warm water** (70–85° F or 21–29° C). It is possible for soft corals to grow in places with warmer or colder water, but growth rates in these types of conditions are very slow.
2. Reef-building corals prefer **clear and shallow water**, where **lots of sunlight** filters through to their symbiotic algae. The most prolific reefs occupy depths of 18–27 m.
3. Corals also need **salt water** to survive, so they also grow poorly near river openings with fresh water runoff.
4. Other factors influencing coral distribution are *availability of hard-bottom substrate* and the *availability of food* such as plankton.

2.1. Location of Coral Reefs

Coral reefs develop in shallow, warm water, usually near land, and **mostly in the tropics**. There are coral reefs off the *eastern coast of Africa*, off the *southern coast of India*, in the *Red Sea*, and off the coasts of *northeast and northwest Australia* and on to *Polynesia*. There are also coral reefs off the coast of *Florida, USA, to the Caribbean, and down to Brazil*.

Student Notes:

The **Great Barrier Reef** (off the coast of NE Australia) is the *largest coral reef in the world*. It is over 2000 km long.

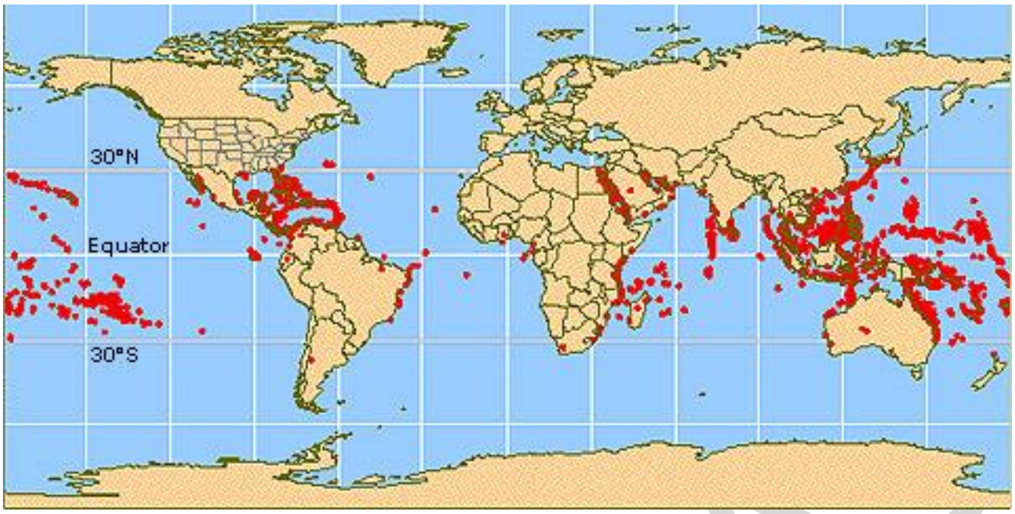


Figure 2. Global distribution of Coral Reefs

2.2. Importance of Coral Ecosystems

- Coral reefs are some of the **most diverse and valuable ecosystems on Earth**. Coral reefs support more species per unit area than any other marine environment, including about 4,000 species of fish, 800 species of hard corals and hundreds of other species. They are often referred to as the **Rainforests of the Sea**.
- Healthy coral reefs have rough surfaces and complex structures that **dissipate much of the force of incoming waves**. This buffers shorelines from currents, waves, and storms, helping to prevent loss of life, property damage, and erosion. Reefs are also a source of sand in natural beach replenishment.
- Being storehouses of immense biological wealth, reefs also provide **economic and environmental services** to millions of people. Healthy reefs contribute to local economies through **tourism**. Diving tours, fishing trips, hotels, restaurants, and other businesses based near reef systems provide millions of jobs and contribute billions of dollars all over the world. Coral reefs serve as habitat for many commercially important species targeted for fishing.
- Coral ecosystems have proven to be beneficial for humans through the identification of potentially **beneficial chemical compounds** and through the development of **medicines**, both derived from organisms found in coral ecosystems. Many drugs are now being developed from coral reef animals and plants as possible cures for cancer, arthritis, human bacterial infections, viruses, and other diseases.

2.3. Threats to Coral Reefs

An estimated 20 per cent of the world's reefs are damaged beyond recovery and about half of the remaining coral reefs are under risk of collapse. The top threats to coral reefs are:

2.3.1. Climate Change

Climate change impacts have been identified as one of the greatest global threats to coral reef ecosystems. As temperature rise, **mass bleaching**, and **infectious disease outbreaks** are likely to become more frequent. Additionally, carbon dioxide absorbed into the ocean from the atmosphere has already begun to *reduce calcification rates in reef-building* and reef-associated organisms by altering sea water chemistry through decreases in pH (**ocean acidification**).

Student Notes:

In the long term, failure to address carbon emissions and the resultant impacts of rising temperatures and ocean acidification could make many other coral ecosystem management efforts futile.

2.3.2. Unsustainable Fishing

Coral reefs and associated habitats provide important commercial, recreational and subsistence fishery resources. But coral reef fisheries, though often relatively small in scale, may have disproportionately large impacts on the ecosystem if conducted unsustainably. *Rapid human population growth, demand for fishery resources, use of more efficient fishery technologies, and inadequate management and enforcement* have led to the depletion of key reef species and habitat damage in many locations.

2.3.3. Pollution

Impacts from land-based sources of pollution (e.g. agriculture, deforestation, storm water, coastal development, road construction, and oil and chemical spills) on coral reef ecosystems include increased *sedimentation*, *nutrients*, *toxins*, and *pathogen introduction*. These pollutants and related synergistic effects can cause disease and mortality in sensitive species, disrupt critical ecological functions, cause trophic structure and dynamics changes (i.e. eutrophic conditions), and impede growth, reproduction, and larval settlement.

These threats—combined with other threats like *coral disease; tropical storms; tourism and recreation; vessel damage; marine debris, and aquatic invasive species*—compound upon each other, making conservation efforts more difficult.

2.4. Coral Reefs in India

The coral reef ecosystems are found in four regions of India which are:

Region	Type of Reef
Andaman & Nicobar Islands	Fringing Reefs
Gulf of Mannar (Tamil Nadu)	Fringing Reefs
Gulf of Kutchh (Gujarat)	Fringing Reefs
Lakshadweep Islands	Atolls

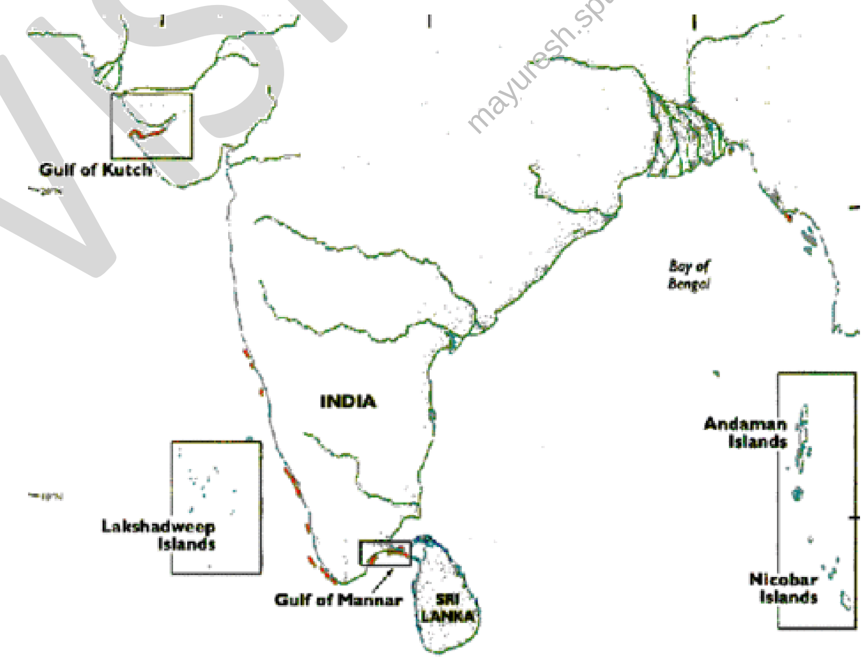


Figure 3. Coral Reefs of India

There are no coral reefs on the central east and west coasts of India. The conditions here, especially **salinity and high sediment load**, are not ideal for coral growth. Most major rivers of India, like the Ganges, flow into the sea on the east coast, bringing in lots of sediments that would not allow the corals to grow. On the west coast, the monsoon is intense from June to August. The fresh water flow into the sea at this time reduces salinity to less than half of the normal and the sea water becomes murky brownish with the sediments.

The Indian coral reefs are world famous but least explored, studied and utilised. On the other hand, they are indiscriminately damaged by human exploitation mainly for the cement industry (calcium carbide), road and building material in certain areas like the Gulf of Mannar and the Gulf of Kutch. The other two regions, the Andaman and Nicobar Islands and the Lakshadweep, because of their far-flung location from the mainland, are comparatively less affected by human depredations.

3. Indian Ocean

The Indian Ocean is the third largest of the world's oceanic divisions, covering approximately 20% of the water on the Earth's surface. It is bounded by Asia—*including India, after which the ocean is named on the north*, on the west by Africa, on the east by Australia, and on the south by the Southern Ocean.

As one component of the World Ocean, the Indian Ocean is delineated from the Atlantic Ocean by the **20° east meridian** running south from **Cape Agulhas** (South Africa), and from the Pacific Ocean by the meridian of **146°55' east**. The northernmost extent of the Indian Ocean is approximately **30° north in the Persian Gulf**. The ocean is nearly 10000 km wide at the southern tips of Africa and Australia, and its area is 73556000 km² including the Red Sea and the Persian Gulf.

Island nations within the ocean are *Madagascar, Comoros, Seychelles, Maldives, Mauritius, and Sri Lanka*. The archipelago of Indonesia borders the ocean on the east.

Figure 4. Geography of Indian Ocean

3.1. Significance of Indian Ocean for India

Significance of Indian Ocean for India can be discussed under following heads:

1. **Geopolitical Significance:** The Indian Ocean Region (IOR), comprising the ocean and its littorals, is India's regional or *immediate geo-strategic environment*. It exists on the fringes of our boundaries and has a significant impact on the internal state of affairs.Indian Ocean defines the Indian Navy's primary Area of Maritime Interest, where it seek to address the challenges having a bearing on national security and the nation's overall socio-economic development.

   With substantial economic activity, including 90% trade by volume and bulk of our energy imports, happening over the sea, **maritime security** is central to overall development of our nation. Concurrently, India cannot hope to develop and grow peacefully with an unstable and turbulent neighbourhood. Prevalence of peace in the Indian Ocean Region is therefore a key national security imperative.

   Riding on the benefits of globalisation, littorals of the IOR are now re-emerging to achieve their original potential. The emergence of many regional countries, as economic powerhouses, reflects this reality. Consequently, several regional economic groupings such as ASEAN, BIMSTEC, SAARC, IOR-ARC, GCC and few others have evolved over time in the IOR to harness the advantages of economic integration.

   India's **geo-strategic location** positions us right at the confluence of major arteries of world trade. The Indian Navy is therefore viewed by some of the littorals as a suitable agency to facilitate regional maritime security in the IOR as a **net security provider**. India's standing as a **benign power** provides credence to this perception, making us a preferred partner for regional security.

   Economic security is central to the comprehensive approach to security. In this globalised world, the Indian economy is integrated with, and consequently interdependent on other world economies. The prospect of disruption of trade at critical chokepoints, such as the Strait of Hormuz or Malacca, can be catastrophic for the global economy. The downstream effects of such economic upheaval are certainly disastrous for regional peace. Maintaining unimpeded flow of energy and other commodities over the sea is therefore a prime concern for all nations, including ours.

   Maritime terrorism is another grave challenge. The events of 26/11 brought to fore the porosity of our long coastline and its resultant vulnerability to terror attacks perpetrated from the sea. Moreover, the prospect of terror attacks on off-shore infrastructure and sea-borne traffic, close to the coast, puts a premium on ensuring **coastal security**. Consequent to government directives, the Navy is now responsible for overall maritime security of the country, including the coast.

   The region's natural bounties and maritime trade carried over its sea lanes drive the global economy. The fact that two-thirds of the world's oil shipments, one-third of its bulk cargo and half of the container traffic transit over its sea lanes, and through its choke points, a large part of which is meant for countries outside the region, underscores the Indian Ocean's importance for the world at large.

   In conclusion, maintenance of a peaceful maritime environment is an imperative, for our nation and the region, to sustain our growth trajectories and to achieve our national aspirations. The oceans are vast, challenges too many, and resources limited, for any individual state to assure security of the global commons. This, therefore, calls for a cooperative approach. By virtue of **India's geo-strategic location** in the Indian Ocean and her **maritime capabilities**, the Indian Navy is deemed by many to be the net security provider in the IOR.

2. **Economic Significance:** Economic importance of the Indian Ocean is immense. It can be discussed on the following points:
   a. About 30% of *world trade* is handled in the ports of the Indian Ocean.
   b. Half of the world's *container traffic* passes through Indian Ocean.
   c. *Continental shelves* cover about 4.2% of the total area of the Indian Ocean and are reported to be very Rich in minerals including Tin, Gold, Uranium, Cobalt, Nickel, Aluminium and Cadmium although these resources have been largely not exploited, so far.
   d. 40 out of 54 types of *raw materials* used by U.S. industry are supplied by the Indian Ocean.
   e. Several of the world's *top container ports*, including Port Kelang and Singapore, are located in Indian Ocean as well as some of the world's fastest growing and busiest ports.
   f. Indian Ocean possesses some of the *world's largest fishing grounds*, providing approximately 15%of the total world's fish catch (approximately 9 million tons per annum).
   g. 55% of known *world oil reserves* are present in Indian Ocean.
   h. 40% of the *world's natural gas reserves* are in Indian Ocean littoral states.

4. UPSC Questions Related to Above Topics

1. What is the importance of Indian Ocean for India? (UPSC 1999/15 Marks)
2. Mention the advantages which India enjoys being at the end of the Indian Ocean. (UPSC 1996/15 Marks)
3. Describe the ideal conditions for coral reef formation. (Geography Mains 2008)
4. Write short note on formation of coral reefs. (Geography Mains 2001/200 words)
5. Write short note on coral reefs. (Geography Mains 1988/200 words)
6. Examine economic significance of the resources of the Continental Shelf of the Indian Ocean. (Geography Mains 2009/30 marks)
7. Assess the geographical significance of Indian Ocean. (Geography Mains 2008/200 words)
8. Analyse the role of India in the geo-politics of the Indian Ocean Region. (Geography Mains 2003,2000/200 words)
9. Discuss the geopolitical importance of Indian Ocean area. (Geography Mains 1999/200 words)