CLASSROOM STUDY MATERIAL

GEOGRAPHY

Part - 1

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GEOGRAPHY PART 1

THE UNIVERSE AND SOLAR SYSTEM

Student Notes:

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.**

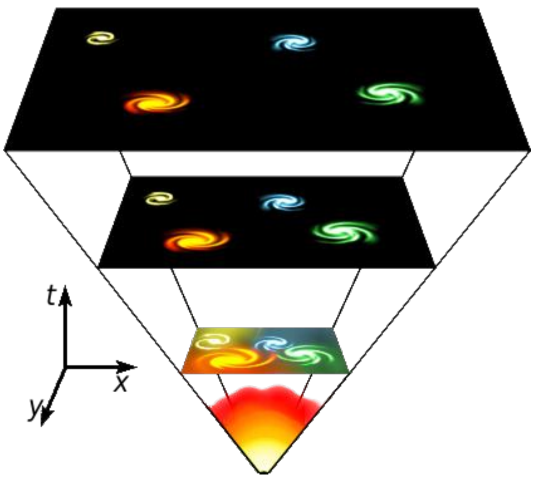
However, with greater evidence becoming available about the expanding universe, scientific community at present favours argument of expanding universe.

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

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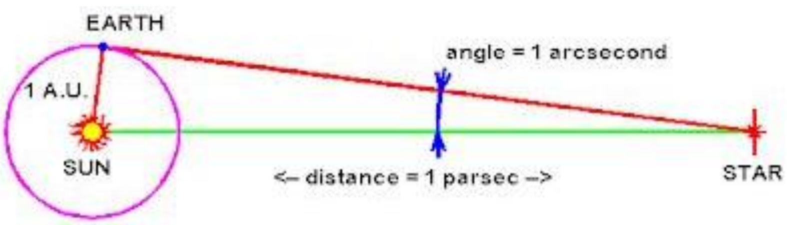
Evidence	Interpretation
The light from other galaxies is red-shifted.	The other galaxies are moving away from us.
The further away the galaxy, the more its light is red-shifted.	The most likely explanation is that the whole universe is expanding. This supports the theory that the start of the universe 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.



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 **:**

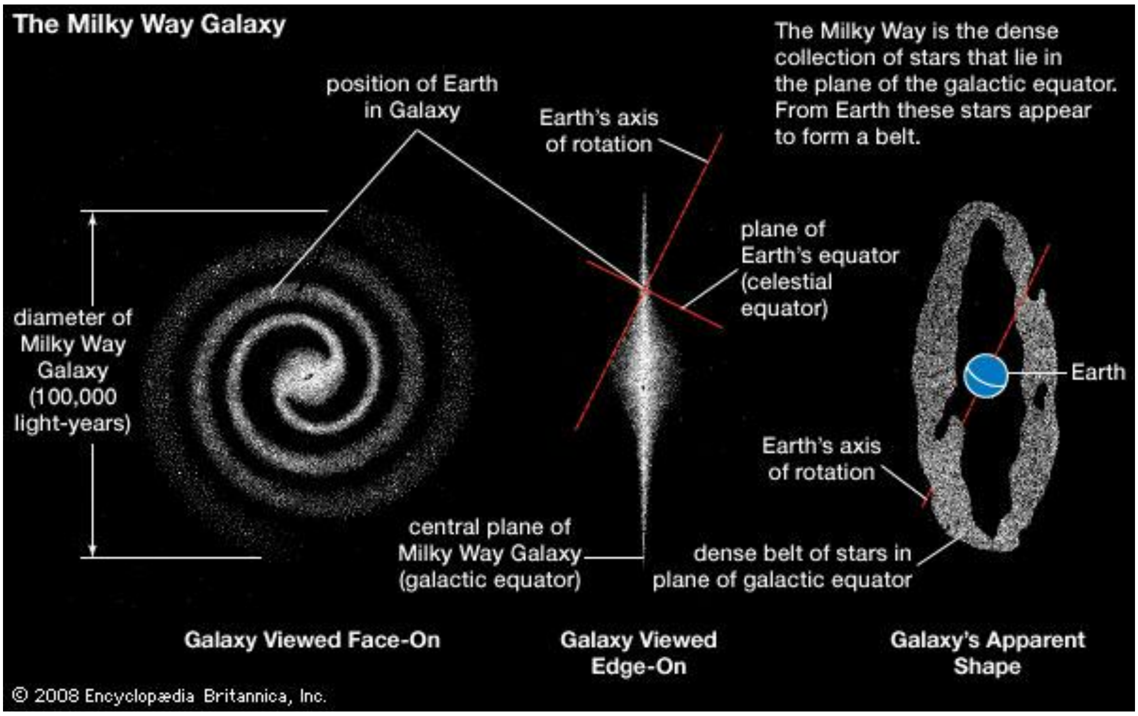
1) Spiral
2) Elliptical
3) Irregular

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 called̍ Akash Ganga̍ .



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 <u>east to west</u> 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.

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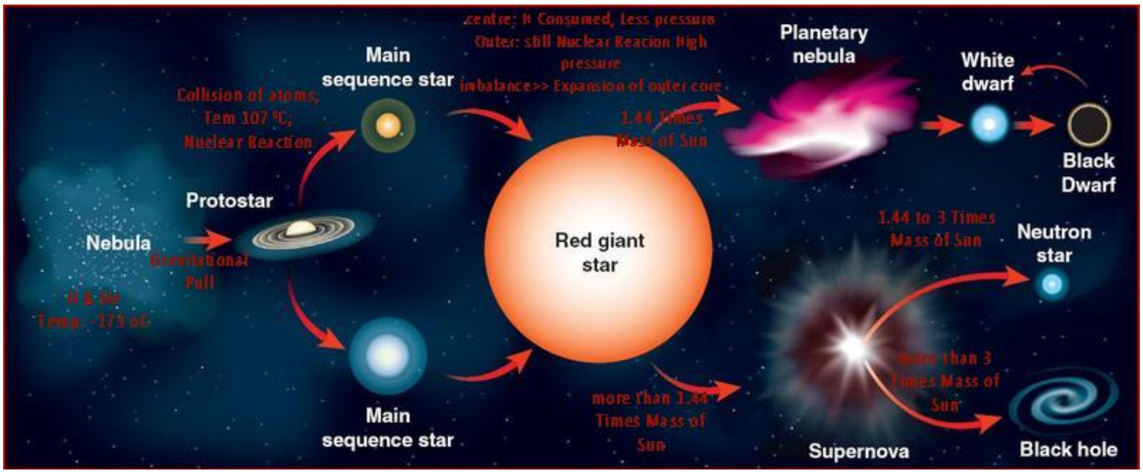
4.1. Birth and Evolution of a Star

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

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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**.

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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

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

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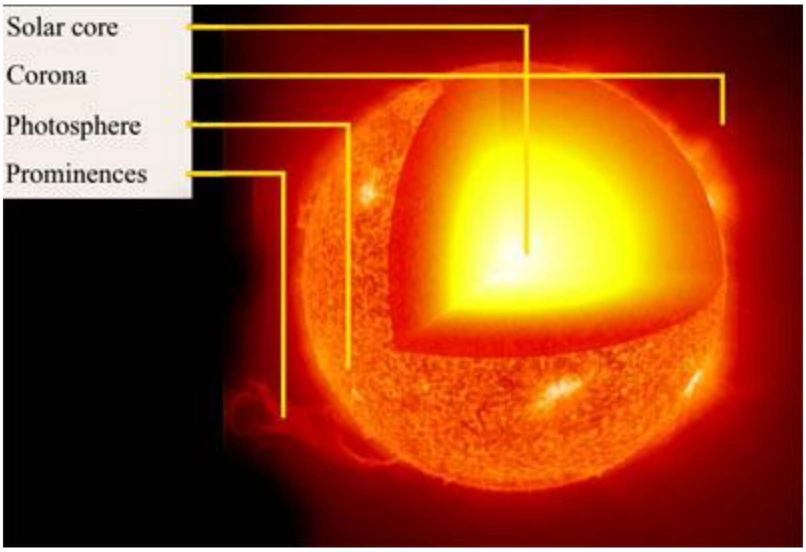
distance of about 27,000 light years from the centre of the Milky Way galaxy and is about 5 billion years old. The sun is at the centre of the solar system and all these bodies are revolving around it. The gravitational pull of the sun keeps all the solar system and all the planets and other objects 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 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)

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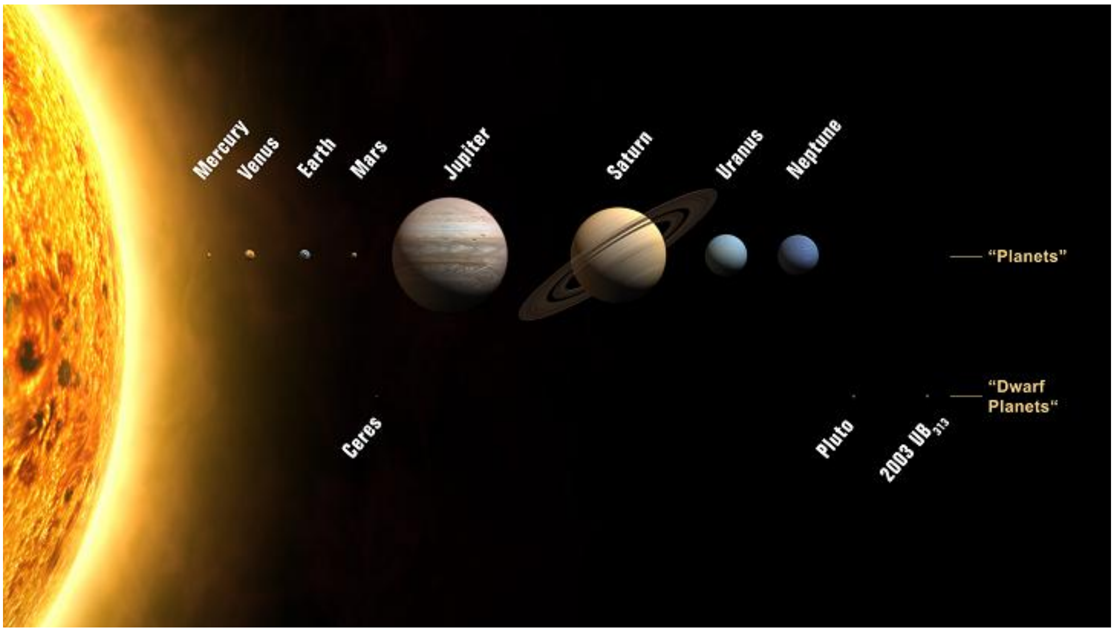
IAU new definition of planet

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.



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 plane**ts 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).

<u>Solar System Fact Sheet</u>

(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
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

Student Notes:

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/)

Student Notes:

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.

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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.

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, CH4 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.

Student Notes:

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 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.

[2] UPSC asked question on Gliese 581g

Student Notes:

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 (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.

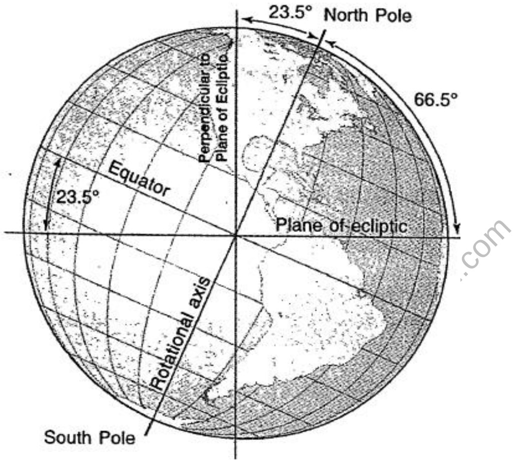
Student Notes:

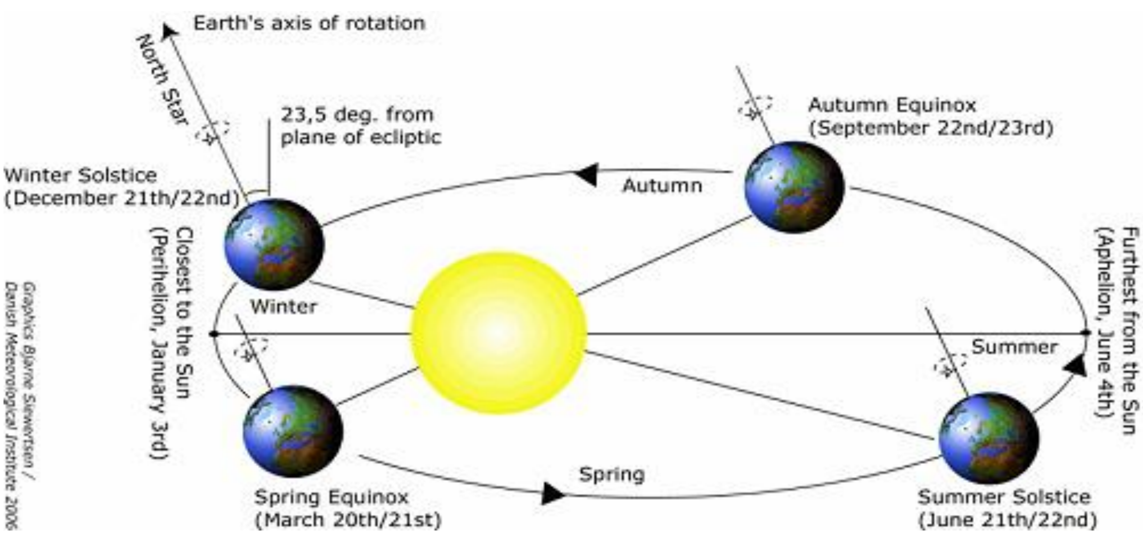
The Earth rotates once in about 24 hours with respect to the sun and once every 23 hours 56 minutes and 4 seconds **with respect to the stars**. This is the reason why the stars rise four minutes early every next day. Earth's rotation is slowing slightly with time; thus, a day was shorter in the past.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

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

Student Notes:

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.

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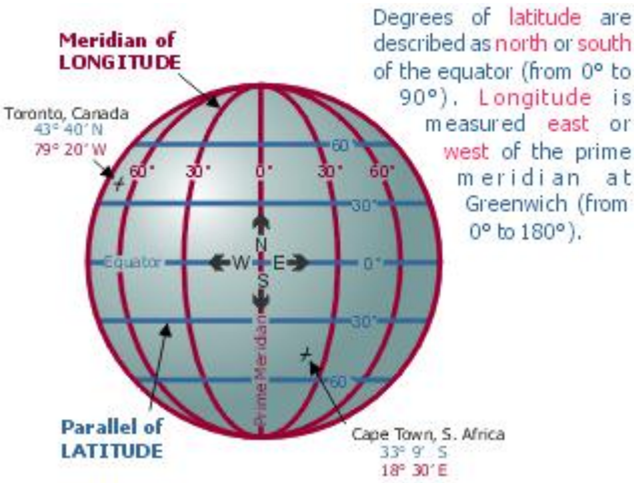


Latitude and Longitude

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.

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,

Student Notes:

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:

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

Student Notes:

10. Previous Years UPSC Prelims Questions

1. In order of their distances from the Sun, which of the following planets lie between Mars and Uranus? (2008)
(a) Earth and Jupiter
(b) Jupiter and Saturn
(c) Saturn and Earth
(d) Saturn and Neptune

2. Which one of the following planets has the largest number of natural satellites or moons? (2009)
(a) Jupiter
(b) Mars
(c) Saturn
(d) Venus

3. What is the difference between asteroids and comets?
1. Asteroids are small rocky planetoids, while comets are formed frozen gases held together by rocky and metallic material.
2. Asteroids are found mostly between the orbits of Jupiter and Mars, while comets are found mostly between Venus and Mercury.
3. Comets show a perceptible glowing tail, while asteroids do not.

Which of the statement(s) given above is/are correct?
(a) 1 & 2
(b) 1 & 3
(c) Only 3
(d) All of the above

4. Electrically charged particles from space travelling at speeds of several hundred km/sec can severely harm living beings if they reach the surface of the Earth. What prevents them from reaching the surface of the Earth? (2012)
(a) The Earth's magnetic field diverts them towards its poles.
(b) Ozone later around the Earth reflects them back to outer space.
(c) Moisture in the upper layers from reaching the surface of the Earth.
(d) None of the statements (a), (b) and (c) given above is correct

Student Notes:

5. A person stood alone in a desert on a dark night and wanted to reach his village which was situated 5 km East of the point where he was standing. He had no instruments to find the direction but he located the pole star. The most convenient way now to reach his village is to walk in the: (2012)
(a) direction facing the pole star.
(b) direction opposite to the pole star.
(c) direction keeping the pole star to his left.
(d) direction keeping the pole star to his right

6. Variations in the length of daytime and night time from season to season are due to: (2013)
(a) the earth’s rotation on its axis
(b) the earth’s revolution round the sun in an elliptical manner
(c) latitudinal position of the place
(d) revolution of the earth on a tilted axis

7. The term 'Goldilocks Zone' is often seen in the news in the context of: (2015)
(a) the limits of habitable zone above the surface of the Earth
(b) regions inside the Earth where shale gas is available
(c) search for the Earth-like planets in outer space
(d) search for meteorites containing precious metals

11. Previous Years Vision IAS Test Series Questions

1. ***What impact does earth's revolution have on hemispherical advent of seasons and on length of the day? In this regard, discuss the concept of Daylight Savings Times (DST) and evaluate its utility in India.***

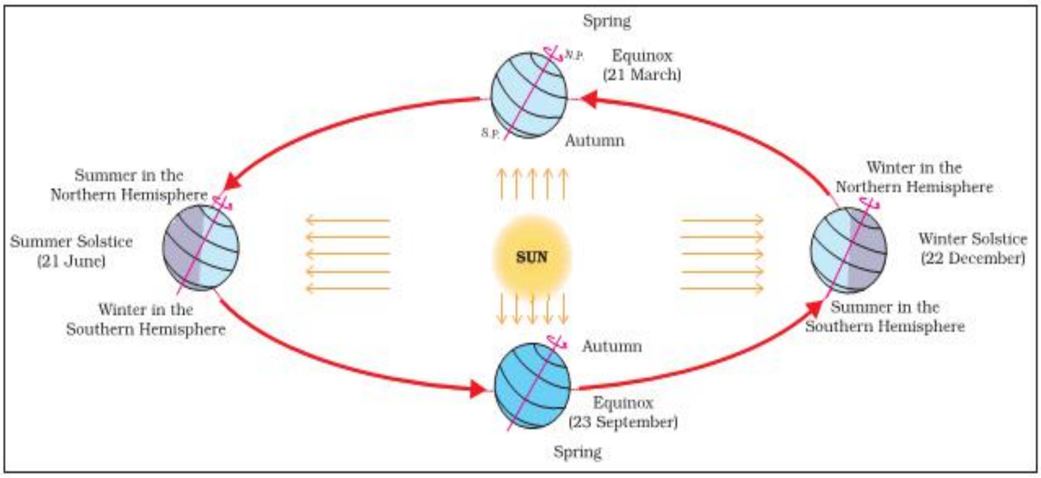
Approach:

- Write separately about the impacts of revolution of earth on hemispherical advent of seasons and on length of the day.
- Explain what is Daylight Saving and why is it used.
- Explain why DST is not used in India.

Answer:

Impact on hemispherical advent of seasons:

- Earth revolves around sun in an elliptical orbit and throughout the orbit, it is inclined in the same direction i.e. 66 ½° to the plane of orbit. This results in change of seasons on the earth due to change in the position of the earth around the sun.



Student Notes:

- On 21st June, the Northern Hemisphere is tilted towards the sun. Since a large portion of the Northern Hemisphere is getting light from the sun, it is summer in the regions north of the equator. At this time in the Southern Hemisphere, all these conditions are reversed. It is winter season there. This position of the earth is called the ***Summer Solstice***.
- On 22nd December, the southern hemisphere is tilted towards the sun. Therefore, it is summer in the Southern Hemisphere with reverse conditions in the Northern Hemisphere. This position of the earth is called the ***Winter Solstice***.
- On 21st March and September 23rd, direct rays of the sun fall on the equator. At this position, neither of the poles is tilted towards the sun; so, the whole earth experiences equal days and equal nights. This is called ***Spring Equinox*** and ***Autumn Equinox*** respectively.

Impact on lengths of the day:

- During the summer solstice, the North Pole is inclined towards the sun. The rays of the sun fall directly on the Tropic of Cancer and regions in the northern hemisphere receive more sunlight for longer time than southern hemisphere. This results in longer days and shorter nights in the northern hemisphere and the length of the day increases towards the northern pole. The places beyond the Arctic Circle experience continuous daylight for about six months.
- The conditions are reversed during winter solstice with the South Pole inclined towards the Sun. The Southern Hemisphere will have longer days and shorter nights.
- During equinox, direct rays of the sun fall on the equator. At this position, neither of the poles is tilted towards the sun; so, the whole earth experiences equal days and equal nights.

Daylight Saving Time (DST):

It is the practice of advancing clocks forward one hour near the start of spring and are adjusted backward in autumn. During the summer months, the sun rises earlier and sets later and there are more hours of daylight. If clocks are set ahead the sun will rise and set later in the day as measured by those clocks. This provides more usable hours of daylight for activities that occur in the afternoon and evening. Daylight saving time can also be a means of conserving electrical and other forms of energy.

Daylight saving time begins in the northern hemisphere between March–April and ends between September–November. Daylight saving time begins in the southern hemisphere between September–November and ends between March–April.

Utility of DST in India:

For tropical and equatorial countries like India, day and night are almost of same length. Thus the practice of advancing clocks will not have much utility in tropical countries like India. Even if it is followed, the daylight time saved in the morning will be lost in the evening.

Though some parts of north India receives more daylight during summer, following DST in some parts and not in others is not a feasible practice.

Student Notes:

2. ***What are the different views on formation of the solar system? Explain how the 'Expanding Universe' theory improves our understanding of formation of the Universe.***

Approach:

- Giving general overview of the solar system, enumerate various views regarding formation of the solar system.
- Thereafter, discuss the expanding universe theory.
- Highlight its importance in understanding the formation of the universe.

Answer:

The solar system consists of the sun, planets, satellites, millions of smaller bodies like asteroids, meteorites and comets and huge quantity of dust-grains and gases. There are several theories related to the formation of the solar system.

Nebular Hypothesis maintains that 4.6 billion years ago, the Solar System was formed from the gravitational collapse of a giant molecular cloud. Most of the mass got accumulated in the center, forming the Sun; the rest of the mass flattened into a proto-planetary disc, out of which the planets and other bodies in the Solar System were formed.

But many scientists have contested Nebular Theory because though the Sun constitutes 99% of the mass of the system; it contains only 1% of angular momentum.

This led to emergence of **Tidal Theory.** Put forward by James Jeans in 1917, the theory postulates that planets were formed due to the approach of some other star to the Sun. This near-miss would have drawn large amounts of matter out of the Sun and the other star by their mutual tidal forces, which could have then condensed into planets.

The **capture theory**, proposed by M. M. Woolfson in 1964, proposes that the Solar System was formed from tidal interactions between the Sun and a low-density proto-star. The Sun's gravity would have drawn material from the diffuse atmosphere of the proto-star, which would then have collapsed to form the planets.

Expanding Universe Theory

Also called, the Big Bang theory, it is the prevailing cosmological model for the birth of the universe. It states that at some moment i.e. about 13.8 billion years ago all of space was contained in a single point. Ever since then Universe has been expanding.

- Observations like the redshift of far-away galaxies viz. “doppler effect in light” supports Big Bang theory. Similarly, Hubbles law i.e. “galaxies appear to be moving away from us at speeds proportional to their distance” serves as an evidence of Big Bang Theory. This observation supports the expansion of the universe and suggests that the universe was once compacted.
- Big Bang suggests that the universe was initially very hot. Cosmic Microwave Background radiation (CMB) which pervades the observable universe is thought to be the remnant of this heat.
- The abundance of the "light elements" Hydrogen and Helium in the universe also support the Big Bang model of origins.

INTERIOR OF EARTH

Student Notes:

Contents

1. Introduction

Student Notes:

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.

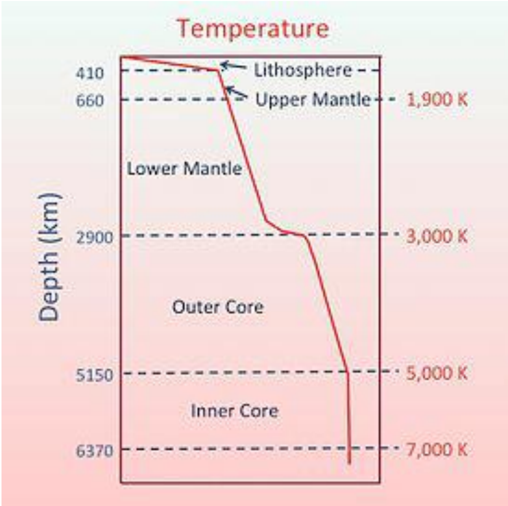


Fig 1: Temperature profile of the inner Earth

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:

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

Student Notes:

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.

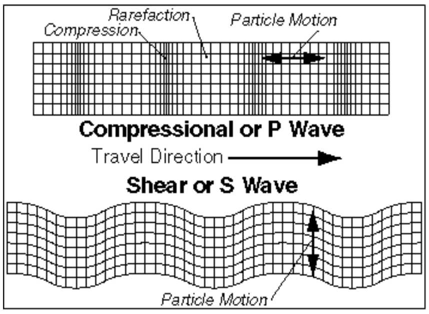


Fig 2: Particle motion in seismic waves

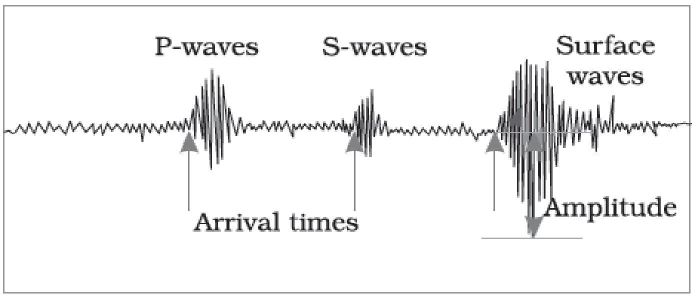


Fig 3: Arrival time of seismic waves

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

Student Notes:

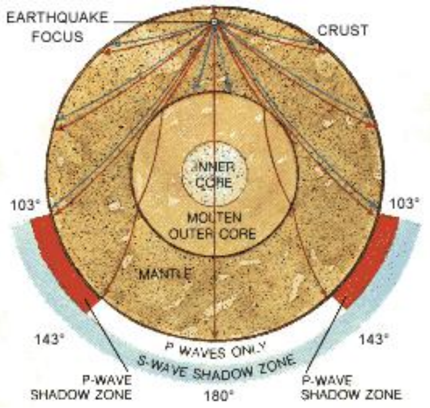


Fig4: Shadow Zones

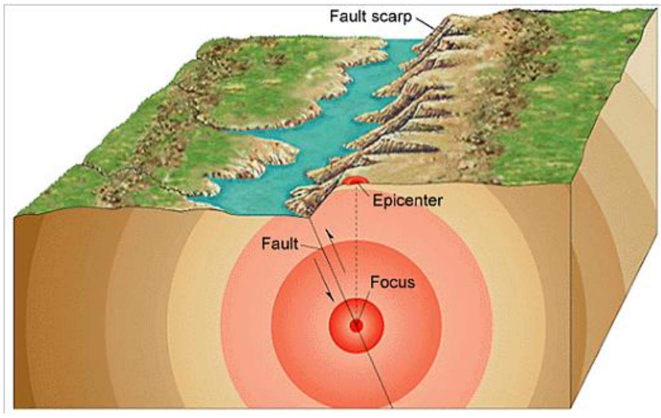


Fig 5: Earthquake

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° 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° to 142°, 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.

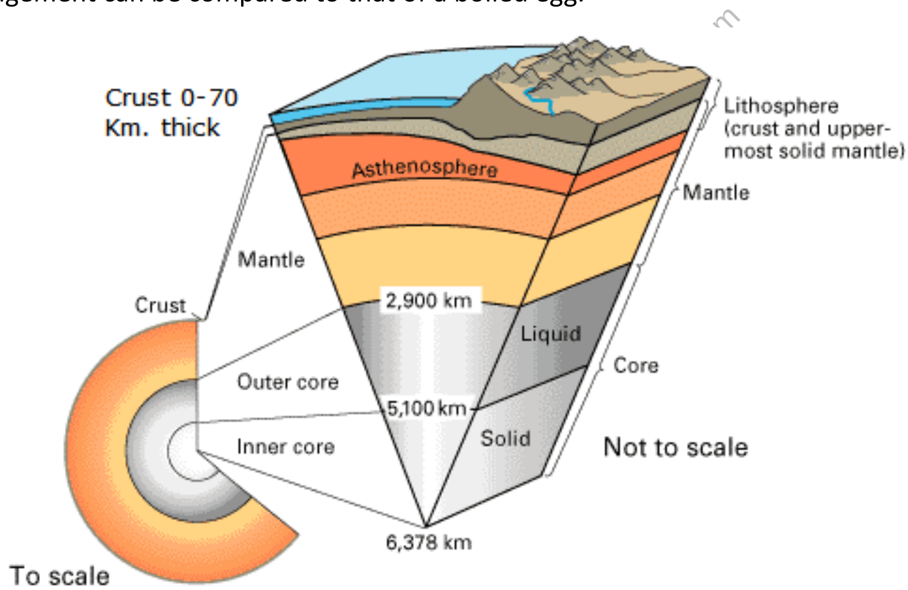


Fig 6

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.

Student Notes:

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.

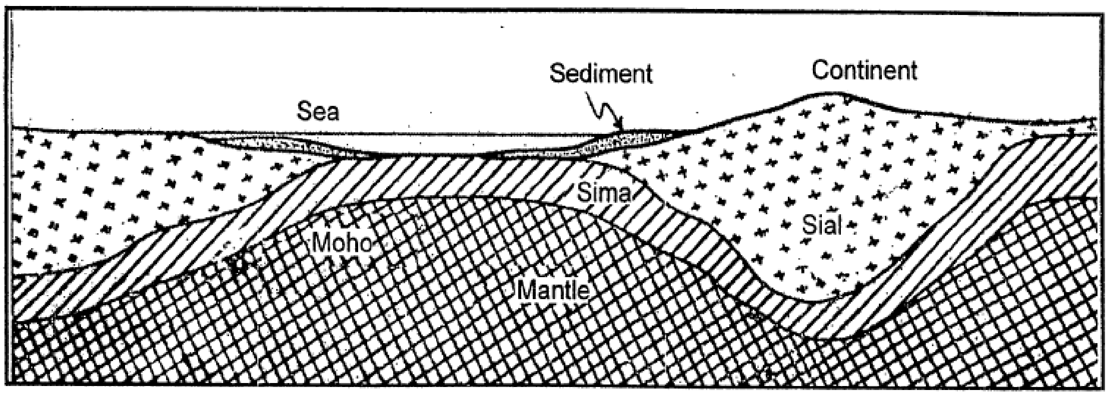


Fig 7: Earth Crust

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.

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.

Student Notes:

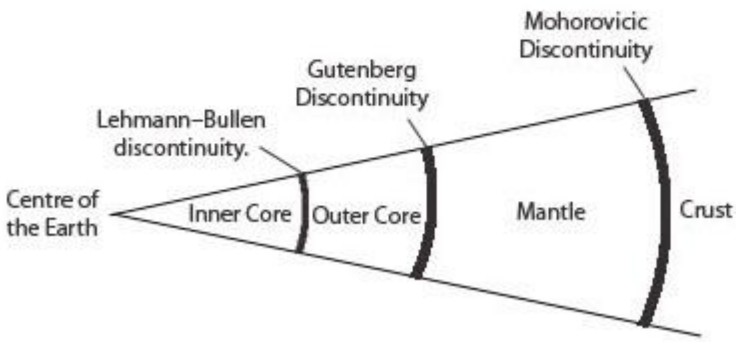


Fig 8: The Discontinuities

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).

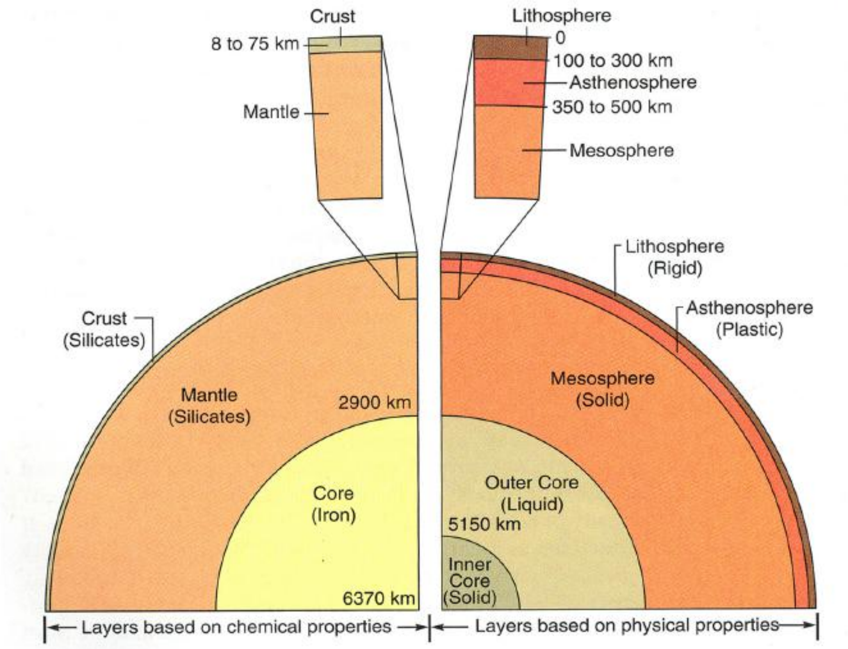
Table 3.1

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
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.



5. Previous Years Vision IAS Test Series Questions

1. Explain the origin of earth's magnetism. Discuss its significance with special reference to its interaction with solar particles as well as artificial satellites.2017-9-856

Approach:

- Introduce the concept of earth's magnetism.
- Explain the origin of earth's magnetism.
- Discuss its significance.

***Answer**:*

Earth possesses the property of magnetism. The magnetic field of Earth is similar to that of a bar magnet tilted 11 degrees from the spin axis of the Earth.

Origin of earth's magnetism

The Earth's magnetic field is attributed to **a dynamo effect** of circulating electric current in the core of the Earth. The rotation of the Earth plays an integral part in generating the currents which are presumed to be the source of the magnetic field.

At the Earth's centre is a solid inner core surrounded by a fluid outer core, which is hotter at the bottom. Hot iron rises within the outer core, then cools and sinks. These convection currents, combined with the rotation of the Earth, are thought to generate a "geodynamo" that powers the magnetic field.

Significance of geomagnetism

The Earth´s magnetic field is important for all forms of life on the planet.

- **Atmosphere protection**: Magnetosphere deflects most of the solar wind, whose charged particles would otherwise strip away the ozone layer that protects the Earth from harmful ultraviolet radiation

Student Notes:

Student Notes:

- **Artificial Satellites**: The deflection of solar storms by Earth magnetic field helps in proper functioning of our communication system. The intense solar wind particles can affect geosynchronous satellites.
- **Rock Dating**: The magnetic reversals provide the basis for magnetostratigrapgy, a way of dating rocks and sediments.
- **Aurora**: Interaction of the terrestrial magnetic field with particles from the solar wind sets up the conditions for the aurora phenomena near the poles
- **Navigation**: Humans have used Earth's magnetic field for navigation purpose since ages. Various organisms ranging from bacteria to pigeons use it for navigation and orientation.
- **Temporal Variation**: The geomagnetic field changes can degrade navigation and surveying techniques; it can impede geophysical exploration; it can disrupt electric power utilities, and pipeline operations; and it can influence modern communications systems, spacecraft.

2. Explain the concept of Diastrophism and elaborate on the processes that form part of it.

Approach:

- Briefly explain the concept of diastrophism including source of energy for this process.
- Elaborate various processes that form part of it.

Answer:

Diastrophism is an endogenic process and consists of all processes that move, elevate or build up portions of the earth's crust. It is the process that brings about changes in the configuration of the surface of the earth. They move, elevate or build up portions of the earth's crust owing to the energy emanating from within the earth. This energy is mostly generated by radioactivity, rotational and tidal friction and primordial heat from the origin of the earth.

Diastrophic movements are categorised into two types:

1. Epeirogenetic
2. Orogenetic

Epeirogenetic movement is the vertical movement of earth's crust, whereas orogenetic is the horizontal movement. *Epeiro* means land, and so these movements are responsible for continent formation. Orogenetic movements are responsible for mountain formation. When magma rises to the surface (vertical movement) and it spreads, continents are formed. Similarly, when a large portion of crust is pushed from below, plateaus are formed. This is known as upwarping. Similarly, on downwarping, basins are formed. In the same manner, block mountains are also formed. On the other hand, during horizontal movement, two plates collide, it leads to formation of fold mountains.

In particular, processes that form part of diastrophism are:

- **Plate Tectonics-** The outer shell of the earth i.e. the lithosphere is broken up into tectonic plates. Plates are classified as major, minor and micro. Plate tectonic is simply the process of horizontal movement of these plates. The current physical map of the world with distribution of continents and oceans is result of plate tectonic process.
- **Orogenic process**- This process takes place when tectonic plates collide, separate or slide along one another. This causes mountain building through severe folding and

affects long and narrow belts of the earth's crust. Some examples of ongoing orogenies are the Mediterranean ridge, Andean orogeny, the Himalayan Orogeny etc.

- **Epeirogenic process-** It is strict vertical movement of a continent rather than horizontal movement. It involves uplifting or warping of large parts of the earth's crust. It lifts the whole region evenly and results in the formation of gentle arches and structural basins.
- **Earthquake-** This process is also a result of tectonic plate movement. This process generates seismic waves which are localized and bring relatively minor movements in Earth's crust.

3. Give an account of the direct and indirect sources which help in deciphering information about earth's interior.

Approach:

- Briefly analyze the present sources of Information about the Earth's interior.
- Explain the direct and indirect sources of information about earth's interior.
- Highlight the limitations of each source and mention about further research that is in progress.

Answer:

Our knowledge of earth's internal characteristics is largely based on estimates and inferences. The sources for information about the interior of the earth are divided into two categories: a) Direct Sources and b) Indirect Sources:

Direct Sources:

- During the process of mining and drilling, rocks and minerals are extracted which gives information that there are layer system in the crust.
- Volcanic eruption suggests that there is a zone inside the earth which is very hot and in semi-liquid condition. However, mining and drilling provide only limited knowledge about the earth's uppermost layers. Direct sources are not very reliable because they are directly applicable only up to a certain depth from earth's surface.

Indirect Sources: Seismic waves, gravitational field, magnetic field, falling meteors etc. are examples of indirect sources.

- Temperature and pressure increase with increasing depth of the earth's interior and that the density of the material increases with depth.
- Gravity anomalies found at different places on the earth's surface provides information regarding the unequal distribution of mass of material in the earth's crust.
- Movement of seismic wave suggests:
- There are three layers in the earth and
- Each layer has different density which increases toward the center of the earth.
- Magnetic surveys give information about the distribution of magnetic materials in the earth's crust.
- Meteors even though not from the earth's interior, may be considered as another source of information.

Besides, the above mentioned sources, scientists are working on "Deep Ocean drilling Project" and "Integrated Ocean Drilling Project" to gather information about the interior of Earth through analysis of materials collected at different depths.

Student Notes:

CONTINENTAL DRIFT AND PLATE TECTONICS

Student Notes:

Contents

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

Student Notes:

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.

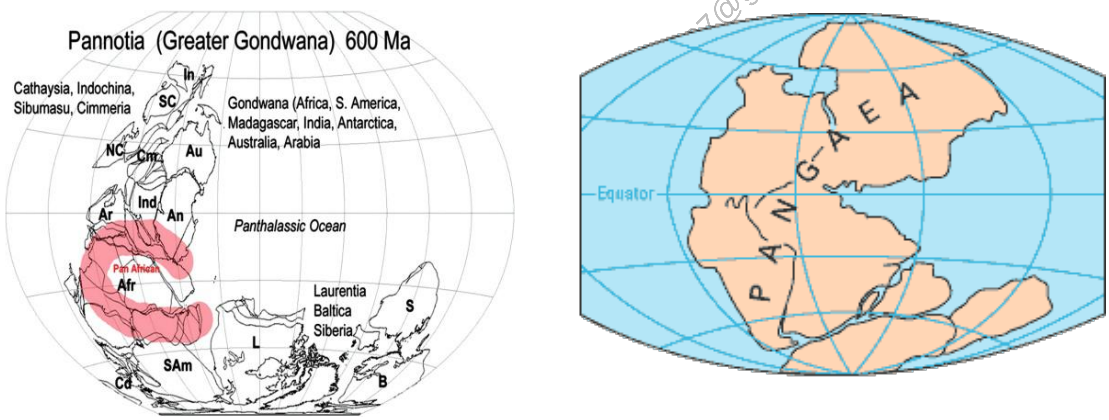
In the past, there existed many supercontinents at different time. The positions of continents have been accurately determined back to the early Jurassic period. However, beyond 200 million years, continental positions are much less certain. Following is the list of supercontinents.

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

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.

Student Notes:

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.

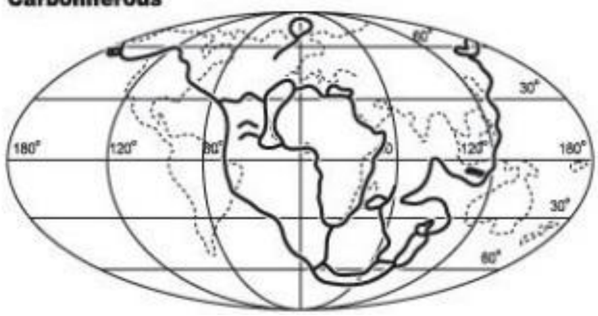
2.1. Continental Drift Theory of Alfred Wegener

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.

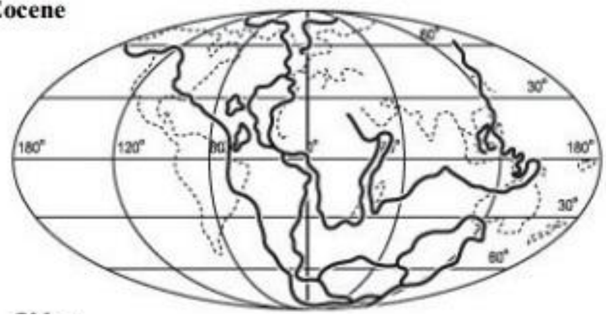
According to Wegener, all the continents formed a single continental mass, a mega ocean surrounded by the same. The super continent was named **PANGAEA**, a Greek word which meant all earth. The mega-ocean was called **PANTHALASSA**, meaning all water as shown in figure 1a. Wegner also imagined that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

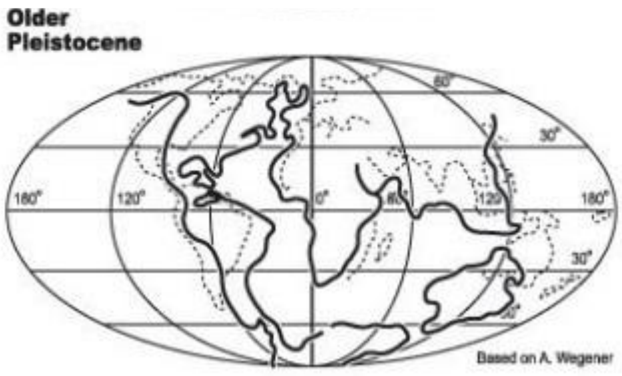
Wegener argued that, around 200 million years ago, the Pangaea began to split. The initial two blocks – Gondwanaland and Laurasia – started drifting away and in between a shallow sea emerged by filling up the water from Panthalasa. It was known as Tethys Sea. The present shape and relative position of 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.

Upper Carboniferous



Eocene





Pangea

Figure 2 – Pangaea

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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.
- **(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.

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

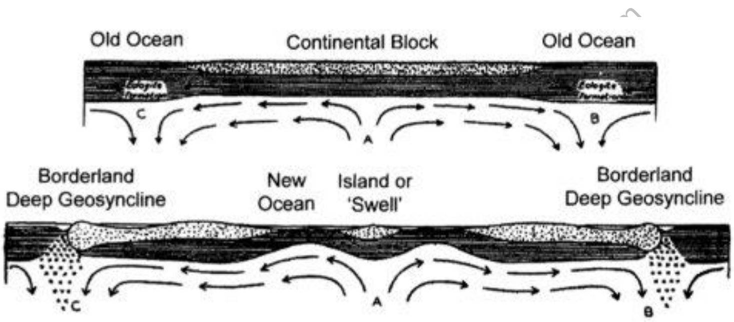

Figure 3 – Convection currents in the mantle portion of the Earth

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

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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.

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

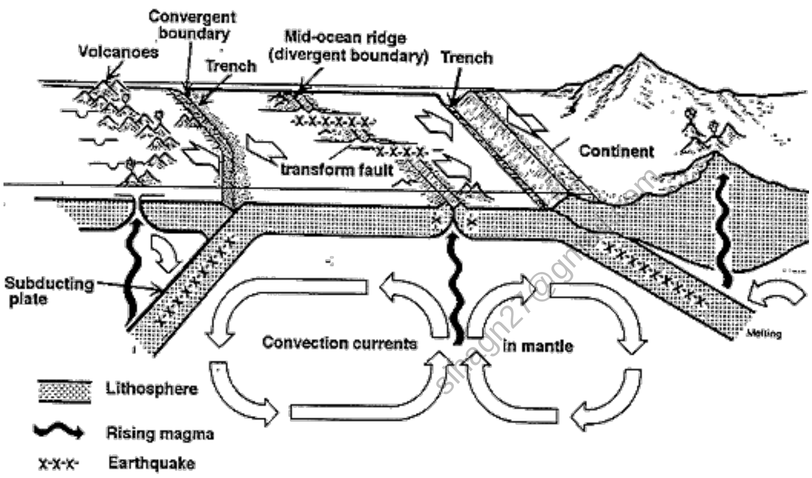

Figure 4 – Sea-floor spreading

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

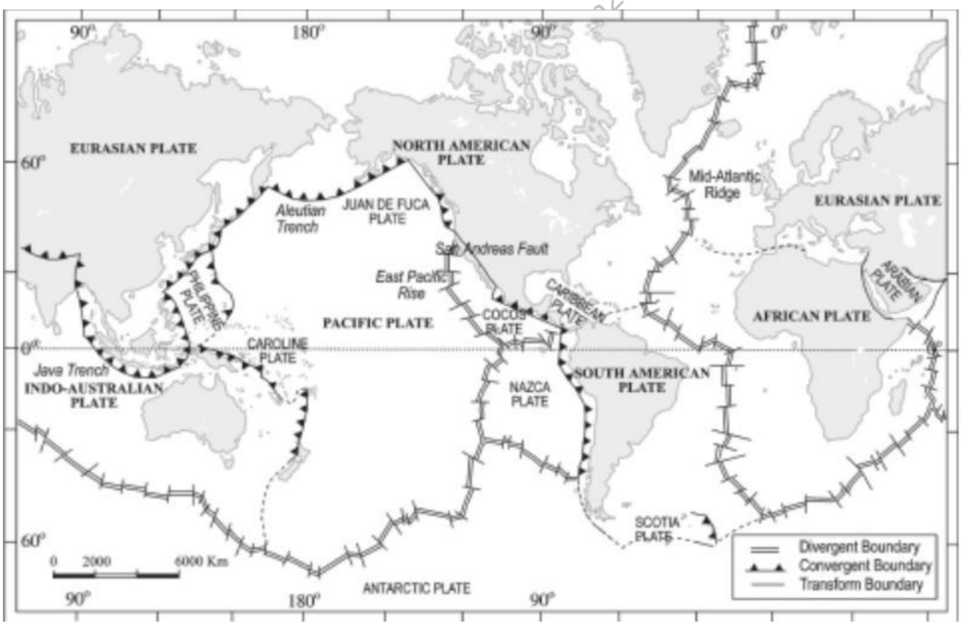

Figure 5 – Major and Minor plates of the world

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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.

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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).

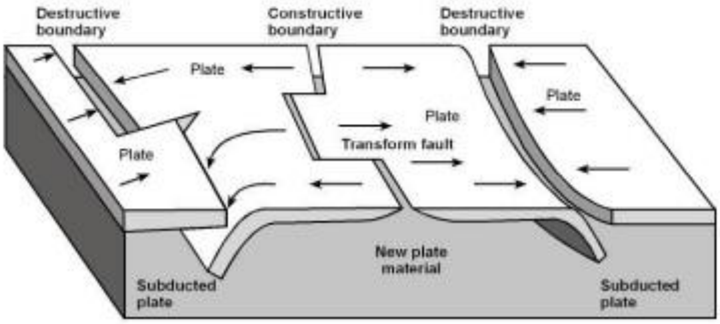

Figure 7 – Types of plate boundaries

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.

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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.
(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:

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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.

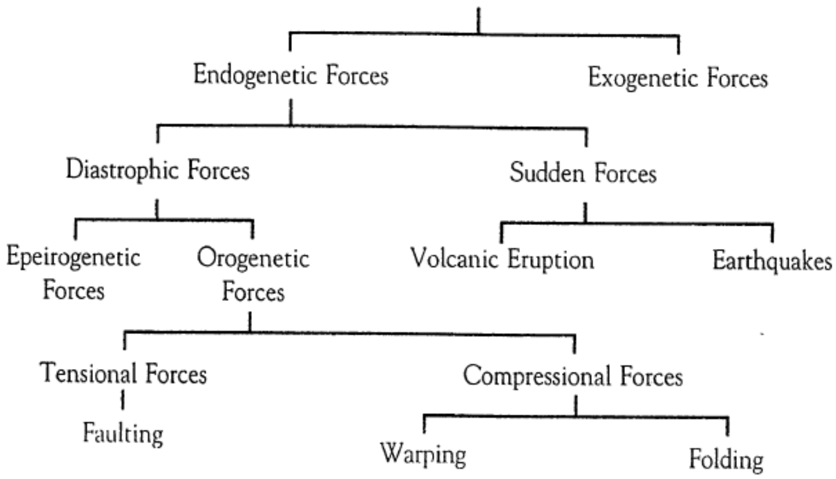
(c) **Earthquake**[1] involves a shock or series of shocks due to sudden movement of crustal rocks within the crust or mantle. Earthquakes are generally associated with boundaries of tectonic plates. There are instances where earthquakes have occurred well inside the tectonic plate. The release of energy 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



[1] earthquakes involving local relatively minor movements.

5.3. Exogenic Processes

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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.

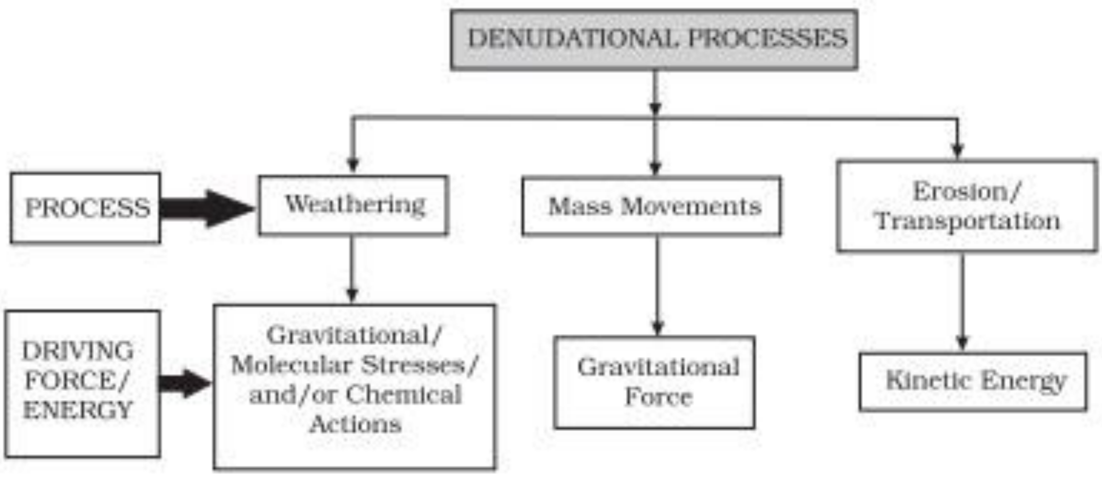

Figure 8 – Denudational process and their driving forces

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.

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- **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 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.

- Expansion by unloading – 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.
- Temperature change and expansion – 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
- Salt weathering – 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.
- Frost action and crystal growth – 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.

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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 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.

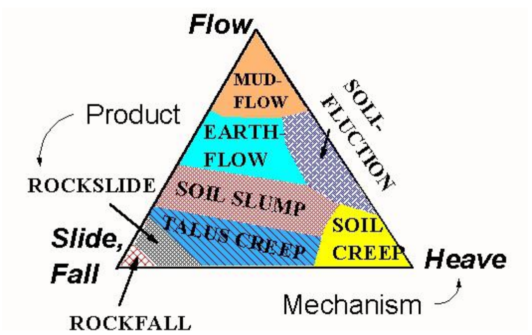

Figure 9 - Relationships among different types of mass movements

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.

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6. Previous Years UPSC Prelims Questions

1. Which of the following phenomena might have influenced the evolution of organisms?
1. Continental drift
2. Glacial cycles

Select the correct answer using the code given below. (2014)

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

7. Previous Years UPSC Mains 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).

3. Define mantle plume and explain its role in plate tectonics. (2018)

8. Previous Years Vision IAS Test Series Questions

1. ***What forces were described as responsible for the movement of the continents as per the Continental Drift Theory? What were the limitations of the Continental Drift Theory? How was the theory of Plate Tectonics an improvement over it?***

Approach:

The question has three parts as follows

- Forces – Rotation of the earth and tidal force
- Limitation – in terms of not able to explained everything about present position and rate of change in the position
- Improvement by new theories – describe sea floor spreading and convectional current theories, which helped in rejection of CDT and were input to the plate tectonics theory.

Answer:

In 1912, Alfered Wegner gave the continental drift theory (CDT). He suggested that the forces responsible for the drifting of the continents are:

- Pole-fleeing force, which is related to the rotation of the earth and is cause for movement towards equator ward.
- Tidal force due to the attraction of the Moon and the Sun – is cause of the westward movement of the Americas.

He believed that these forces would become effective when applied over many million years. Wegner collected several evidences in support of CDT. However, it was based on speculations and inadequate evidences. Few of its limitations are as follows:

- The greatest criticism has been of the forces that he hypothesized as responsible for movements of continents. Tidal force need to be ten thousand million times stronger to move the continents.
- Pole-fleeing force was acting towards equator and thus, continents were supposed to stop at equator.
- He proposed that Rockies and Andes mountain chains were formed during the westward drift of Americas. But then the SIMA could not offer so much resistance to SIAL (continents) to cause folds and build mountain system.
- The jig-saw-fit of the opposing coasts of Atlantic Ocean was not so complete.
- Wegner believed that Pangaea was intact until the late Carboniferous period which is not true.

A number of new discoveries added new information to geological literature. The hypothesis of sea floor spreading established that the ocean rocks are much younger and thinner than the continental rocks. Arthur Holmes suggested that the mantle of the Earth has convectional currents. This explained the issue of force.

Above explained theories revived the question of distribution of ocean and continents. Earth's crust is consists of tectonic plates. It is the plates which move rather than continents. It is not the SIAL and SIMA but Lithosphere and asthenosphere. Both ocean and continents can be part of a single plate or different plates.

The plate tectonics is a great unifying concept which draws sea-floor spreading, convectional current, CDT, crustal structures and world pattern of seismic and volcanic activity together as aspects of one coherent picture.

2. *How does the plate tectonics theory help explain the formation of Himalayas and Deccan Traps?*

Approach:

- Briefly write about Plate Tectonics Theory (PTT) – Only give theoretical background - Describe different plate interactions and landforms associated. No need to enlist different plates, etc.
- Apply the PTT to explain separately the formation of Himalayas and Deccan Traps.
- Draw diagram of movement of Indian Plate.

Answer:

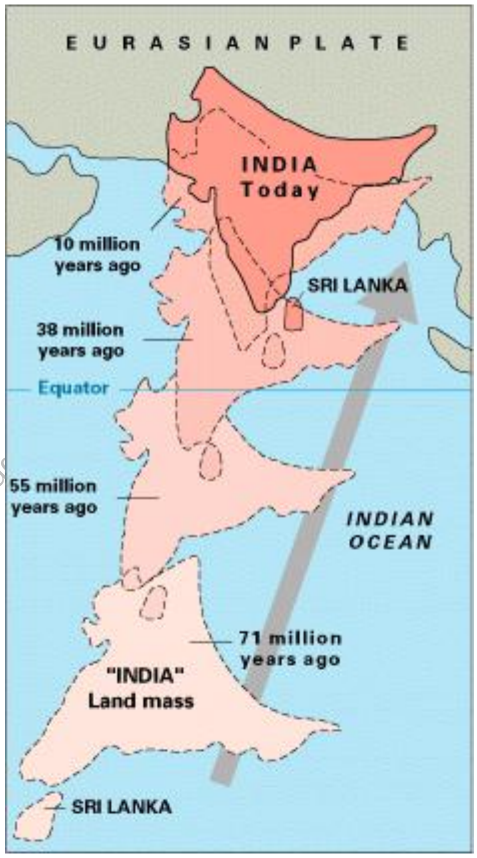

Plate Tectonic Theory (PTT) attempts to describe movements of lithospheric slabs on the surface of earth and their interactions which produce different landforms. A plate is a massive, irregularly-shaped slab of solid rock, generally composed of both continental and oceanic lithosphere.

Converging plates produce landforms like trenches, volcanic arcs, fold mountains, etc. Diverging plates produce mild, consistent volcanism, mid-oceanic ridges, faults, etc. Converging plate boundaries are called destructive boundaries because lithosphere is destroyed (due to subduction), whereas diverging boundaries are called constructive because new crust is created.

According to PTT, the collision of Eurasian and Indian plates about 60-30 million years ago squeezed the sediments deposited in the Tethys Sea, which were folded into Himalayan mountain systems. The northward moving Indian Plate first subducted and then joined under Eurasian Plate at the Indo-Tsangpo Suture Zone. Subsequent periodic thrusts have raised parallel ranges of the Himalayas viz. Greater Himalayas, Middle Himalayas and the Shivaliks. The Indian plate is still pushing and hence, the Himalayas are still rising.

During its movement towards the Asiatic plate, the Indian Plate passed over Reunion Hotspot near Mauritius (about 60 million years ago). Hotspots are regions where

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basaltic lava from outer mantle pours out. Basaltic lava is less viscous and therefore spreads more. This volcanic eruption was of fissure type and continued steadily for long periods. This lead to formation of Deccan Traps (Treppen = Steps), which are step like formations representing different layers of solidified lava.

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3. Explain the phenomenon of Sea Floor Spreading. Analyse how this discovery acted as a precursor to the development of Plate Tectonics Theory.

Approach:

- Explain SFS with evidences and observations.
- Discuss discoveries and aspects like paleomagnetism that SFS was not able to explain, and how the PTT evolved incorporating these new concepts.

Answer:

Sea floor spreading is a process that occurs at mid-oceanic ridges, where new oceanic crust is formed through volcanic activity and then gradually moves away from the ridge. Seafloor spreading helps explain continental movements in the theory of plate tectonics.

The concept of sea floor spreading was first propounded by Harry Hess in 1960. The mapping of the oceanic floor and palaeomagnetic studies of rocks from oceanic regions revealed the following facts:

- It was realised that all along the mid-oceanic ridges, volcanic eruptions are common and they bring huge amounts of lava to the surface in this area.
- The rocks equidistant on either sides of the crest of mid oceanic ridges show remarkable similarities in terms of period of formation, chemical composition and magnetic properties.
- Rocks closer to the mid oceanic ridges have normal polarity (i.e. that of earth) and are the youngest. The age of the rocks increase as one moves away from the crest.
- The ocean crust rocks are much younger than the continental rocks.
- The sediments on the ocean floor are unexpectedly very thin.
- The deep trenches have deep seated earthquake occurrences while in the mid oceanic ridge areas, the quake foci have shallow depths.

On the basis of the above factors, Hess conceptualised that 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. The ocean floor thus spreads.

On the basis of the evidence of palaeomagnetism and sea floor spreading it has been now validated that the continents and ocean basins have never been stationary or permanent at their places rather these have always been mobile throughout the geological history of the earth and are moving in relation to each other.

E.g.: Mediterranean Sea is the residual of once very vast ocean (Tethys Sea) and the Pacific Ocean is continuously contracting because of gradual subduction of American plate along its ridge.

E.g.: Indian Ocean did not exist before cretaceous period. Indian plate began to move towards Asiatic plate through 'Tethys sea' and Australian-Antarctic plates after breaking away from African plate began to move southward during cretaceous period.

Through evidences presented by deep crustal drilling and paleo-magnetic studies on ocean deposits, Sea Floor Spreading was further expanded and a new Plate Tectonic Theory was advanced by Tuzo Wilson, Morgan, et al in 1960s. A plate is a massive, irregularly-shaped slab of solid rock, generally composed of both continental and

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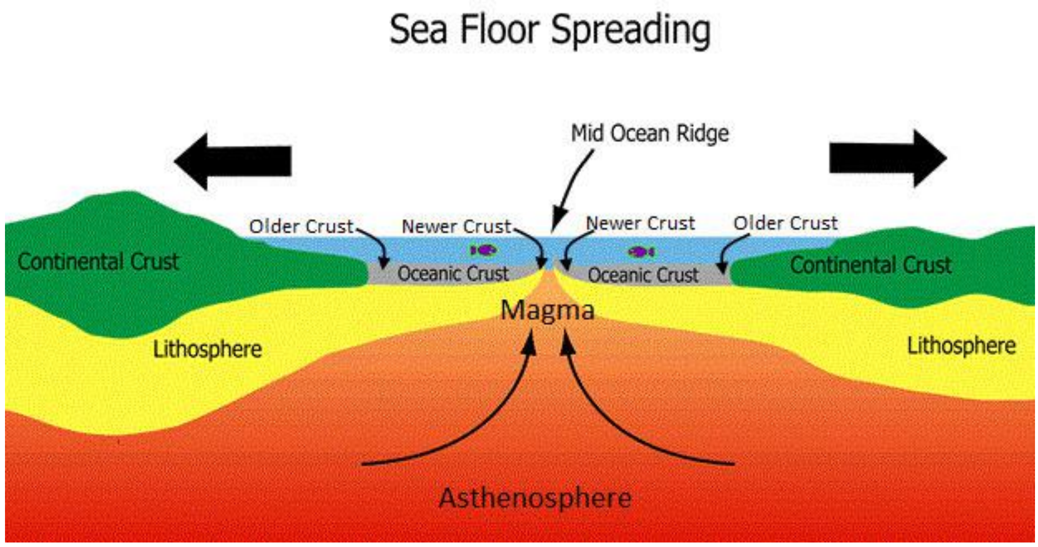
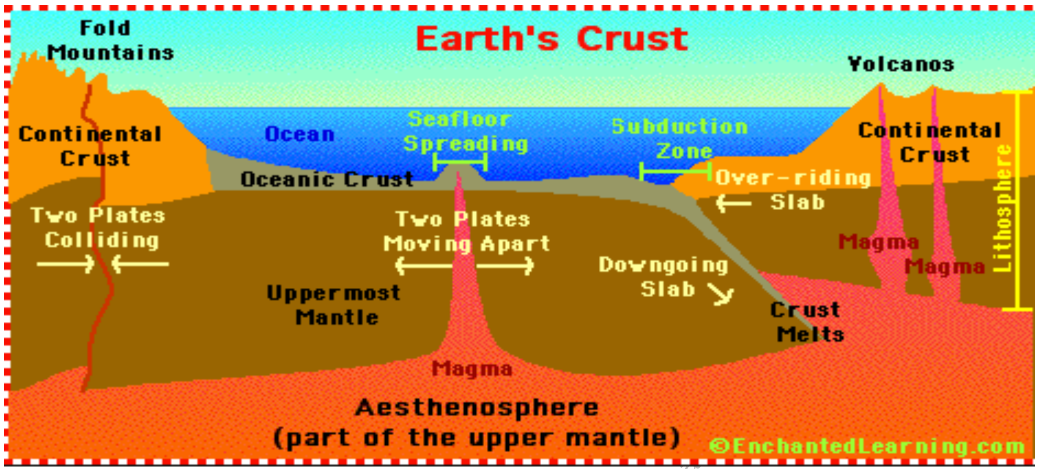
oceanic lithosphere. Plates moves horizontally over the asthenosphere as rigid units and interact with each other. Based on density and margin of interaction, the heavier plates subduct under the lighter plates and give rise to new landforms.





4. ***What is palaeomagnetism? Explain how it serves as a bridging evidence for Plate Tectonics Theory.***

Approach:

- Define paleomagnetism.
- Briefly discuss Plate Tectonics Theory.
- Discuss how paleomagnetism serves as a bridging evidence for the Plate Tectonics Theory.

Answer:

Paleomagnetism is the study of the record of the Earth's magnetic field in rocks and sediments formed over a period of earth's life. Some rocks contain minerals that respond to the magnetic field and when these rocks form, the minerals align with the magnetic field of the earth at the time of their formation, preserving their positions. This allows the paleomagnetists to date the rocks and map the position of the field at the time of their formation.

The **Plate Tectonics Theory** states that the Earth's lithosphere is divided into seven major and some minor lithospheric plates which move horizontally over the asthenosphere as rigid units due to convection currents in the magma.

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Paleomagnetic evidence to support Plate Tectonics Theory:

- **Polar wandering** - Magnetic minerals on one continent do not point to the same pole position as do those from the same time period on another continent. So, there were either multiple north poles during the same time period or that the continents moved in relation to a single north pole. Geophysicists concluded that the magnetic poles remained stationary, and the continents, after splitting apart, diverged along different paths.
- Paleomagnetism is also used to match once joined landmasses that are now separated. For example, the orientation of magnetic minerals along the eastern coast of South America very closely matches that of similar minerals on the western coast of Africa.

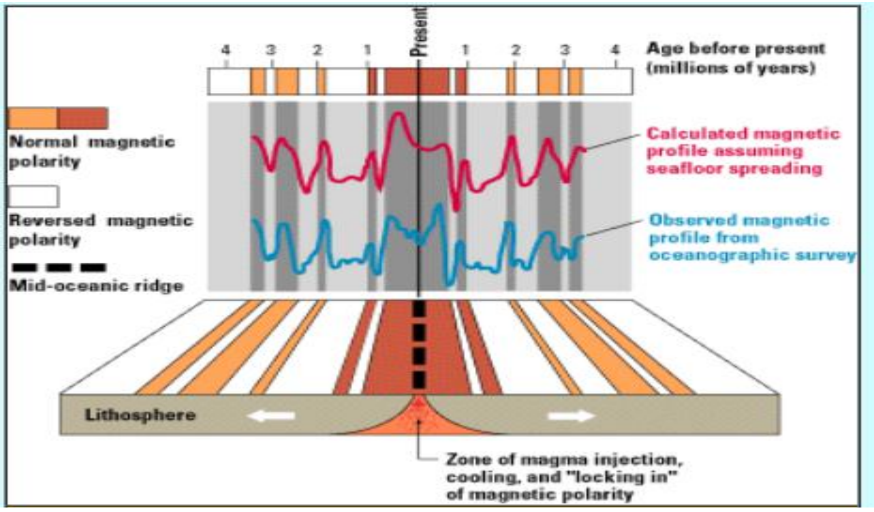

Figure: Ocean Floor Magnetization

- **Polar reversal**: Rocks closer to the mid-oceanic ridges are youngest, have normal polarity. As the "plates" on each side of the Ocean ridge are pulled away, lava emerges from the middle, solidifies and "records" the prevailing magnetic field. Every half million years, on the average, the Earth's magnetic polarity reverses and therefore each strip of basaltic rocks on the ocean floor represents an epoch of one or the other magnetic polarity. This observation was consistent with both sea-floor spreading and Plate-tectonics.

Paleomagnetic evidence, both reversals and polar wandering data, was instrumental in verifying the theory of plate tectonics.

5. ***What are the forces that drive the movement of lithospheric plates? In this context, identify the different types of plate boundaries based on their nature of interaction with suitable examples of the characteristic features formed along them.***

Approach:

- Giving a brief concept about plate tectonics and its movement, explain the forces that are driving them.
- Classify different types of plate boundaries based on their nature of interaction, give examples of varying features found at these boundaries.

Answer:

A tectonic plate is a massive, irregularly shaped slab of solid rock, generally composed of both continental and oceanic crust. According to the most accepted Plate Tectonic Theory, these plates have been moving and interacting with each other in the past and will continue to do so in future, leading to formation of new land and oceanic features.

Reason for the Tectonic Plate Movement

The molten magma rises from depth and spreads laterally below the crust. While spreading, it moves the overlying plate along with it. The molten magma then sinks back, completing a cyclical motion. The molten magma beneath the lithospheric plates is kept molten from the heat released from the radioactive decay in this region and from the residual heat coming from higher depths.

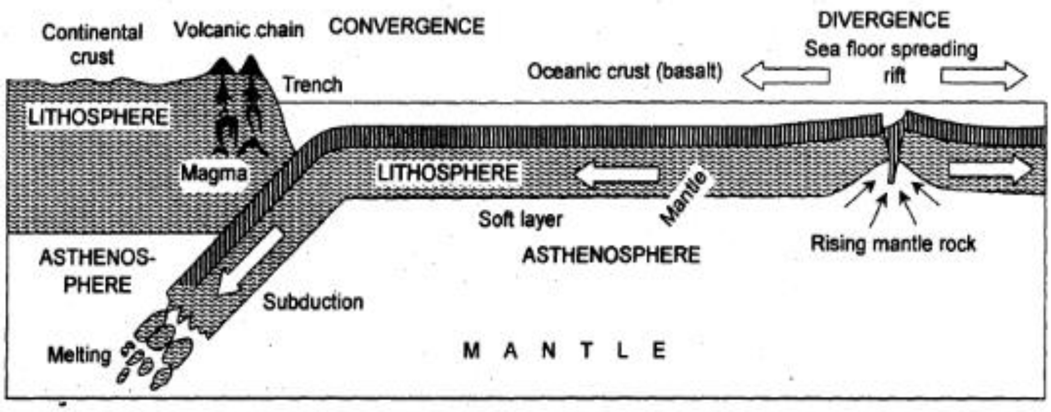

Fig. 5.9 : Diagramatic presentation of different types of plate margins.

The two basic processes that operate in movement of the plates are:

- Ridge push
- Slab pull

The ridge push is the pushing movement along the mid-oceanic ridge where the magma is able to penetrate the lithosphere and hence, pushes the fractured plate laterally.

Slab pull occurs along the trenches or subduction zones where the underlying plate moves down due to gravity and progressively pulls down the plate.

Earlier, the tidal forces of the Sun and the Moon were also thought to be the driving force. However, their effects have not yet been clearly established.

Different types of plate boundaries based on their nature of interaction are:

Plate boundaries are designated based on the margins of interaction, such as ocean ocean, ocean-continent and continent-continent. At these margins, the plates may collide, diverge or slide past each other. This gives rise to various types of plate boundaries:

- **Divergent boundaries-** At these boundaries, plates pull away from each other and new crust is generated at these places. For example, divergent boundaries in the Mid- Atlantic Ridge, where the American plate is separated from Eurasian and African plates.
- **Convergent Boundaries-** At these boundaries, crust is destroyed as one plate dives under another at the subduction zone. When two oceanic plates or a oceanic and continental plate converge, the heavier oceanic plate is subducted and a trench is formed. In case of continent-continent collision, fold mountains and plateaus are formed. This type of margin is characterised by intense folding and faulting and frequent earthquakes.
- **Transform boundaries-** Where the crust is neither produced nor destroyed as the plates slides horizontally past each other. Transform faults are the planes of separation generally perpendicular to the mid oceanic ridges.

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

Student Notes:

Contents

1. Earthquakes

Student Notes:

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.

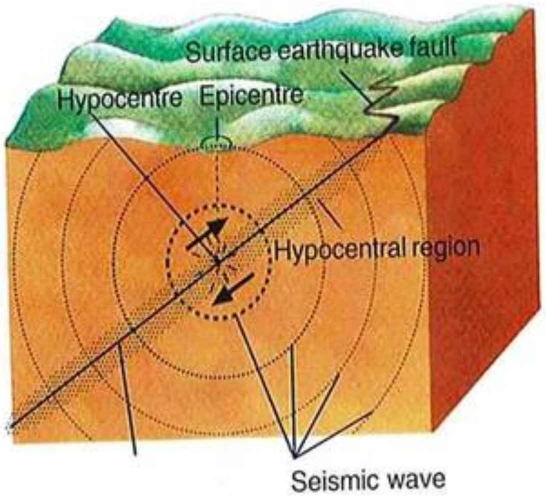

Figure 1: Hypocentre and Epicentre

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.
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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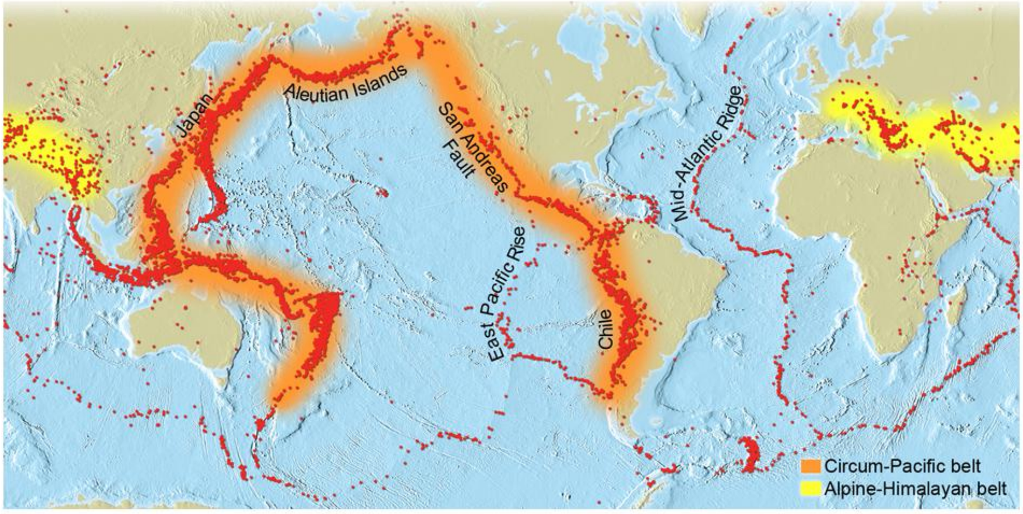

Distribution of nearly 15,000 earthquakes with magnitudes equal to or greater than 5 for a 10-year period.

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.

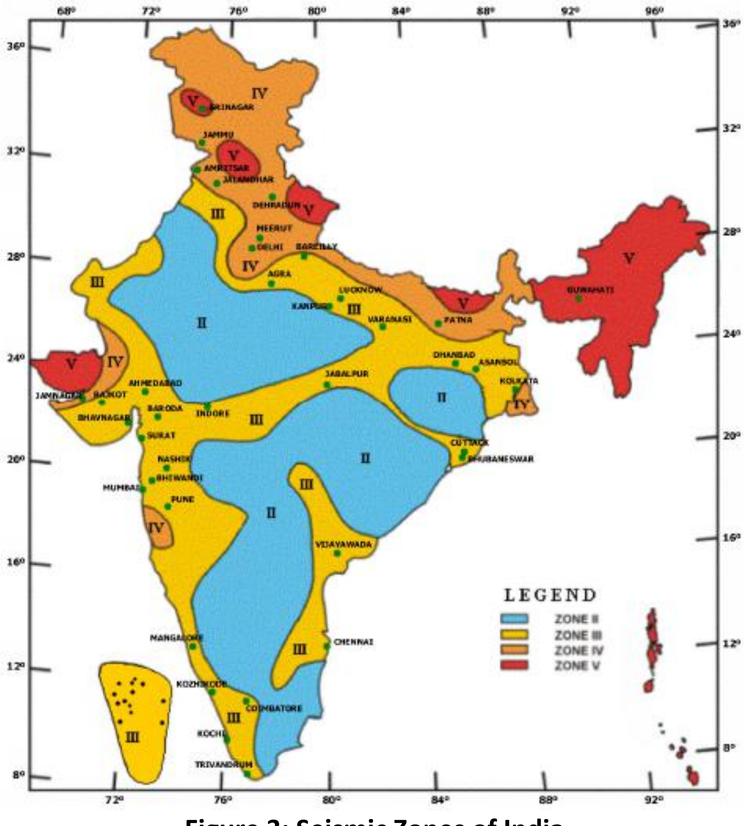

Figure 3: Seismic Zones of India

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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.

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.

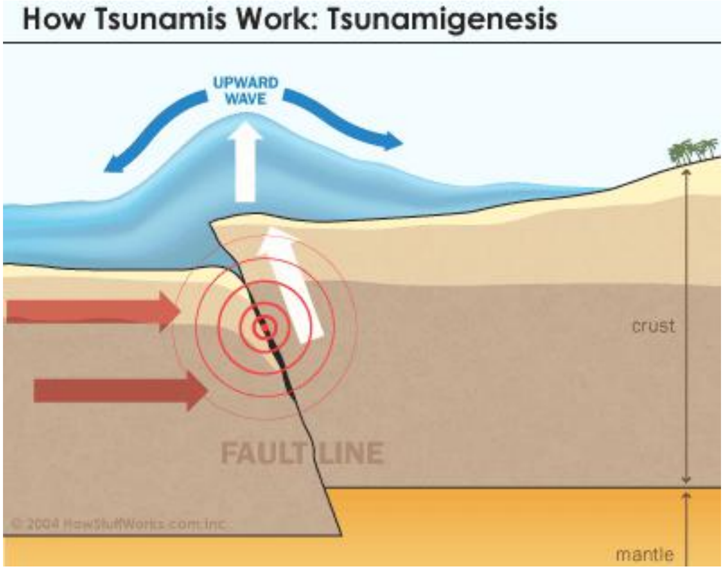

Figure 4: Generation of Tsunami

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.

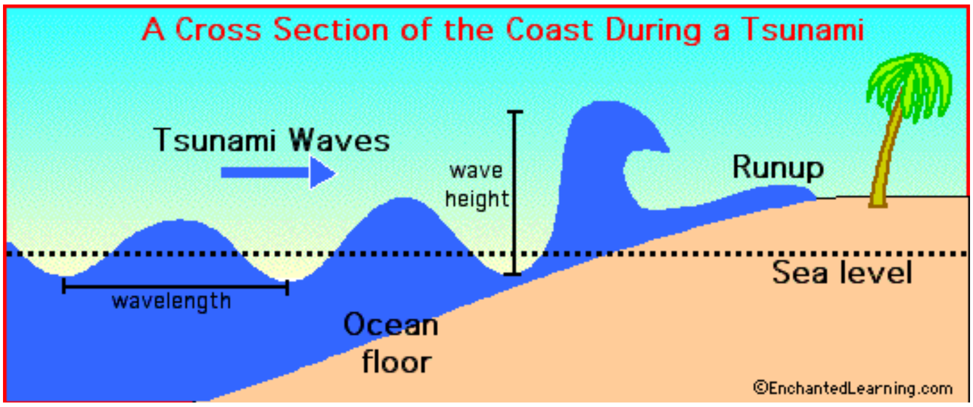

Figure 5: Rise in Tsunami amplitude near the coast

Student Notes:

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.

Student Notes:

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**.

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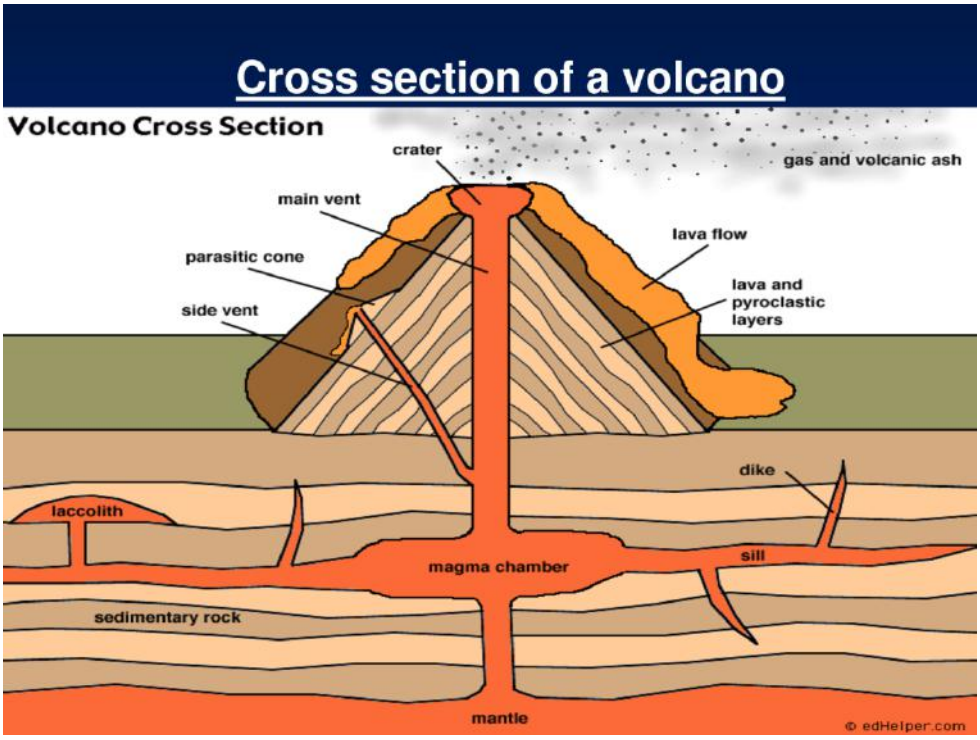

Figure 6: Components of a volcano

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

Student Notes:

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.

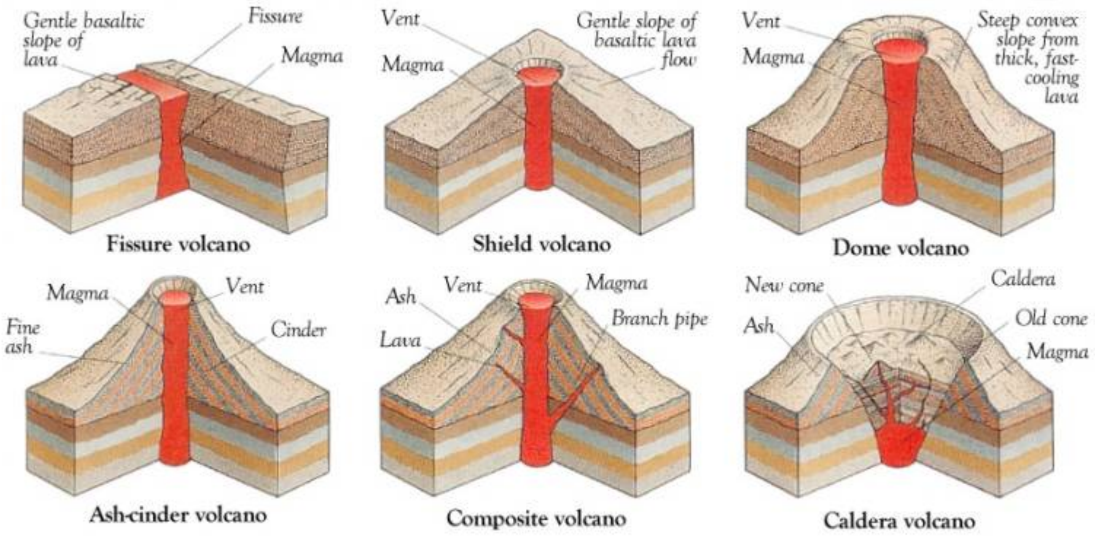

Figure 7: Volcanoes based on extrusive landforms

3.4.2. Intrusive Landforms

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

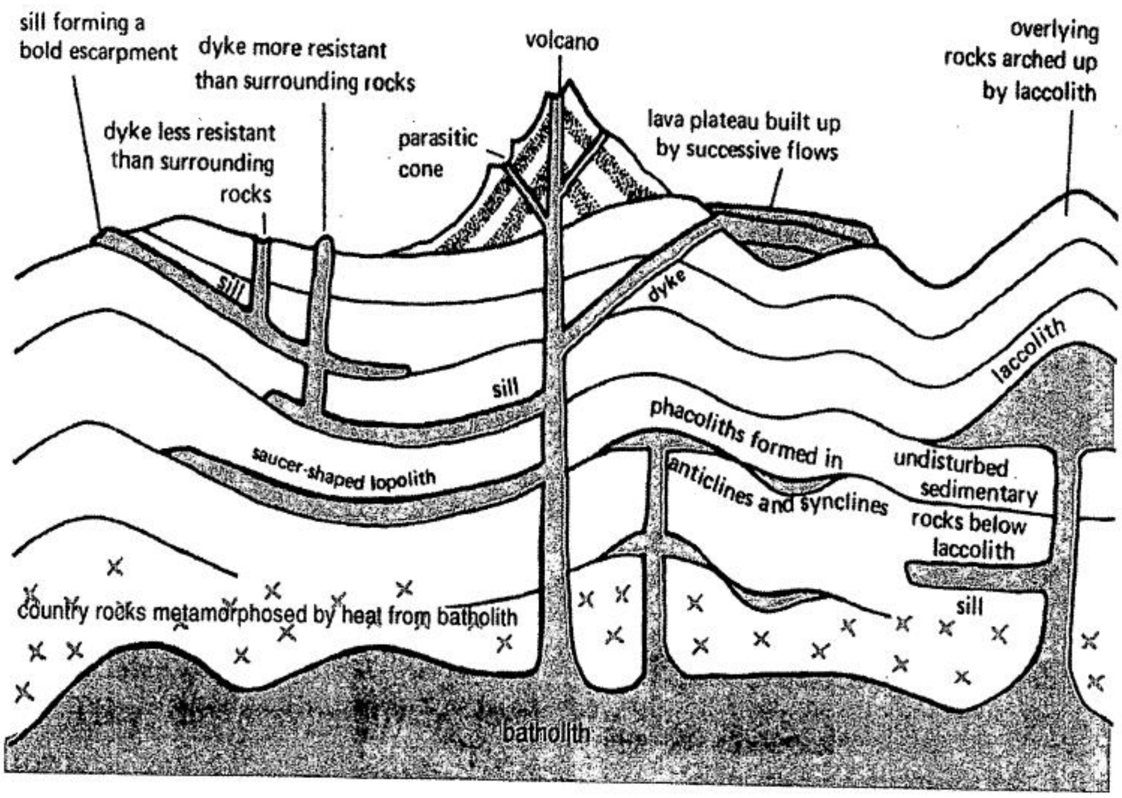

Figure 8: Various intrusive landforms formed in volcanic regions

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.
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.

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Student Notes:

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.

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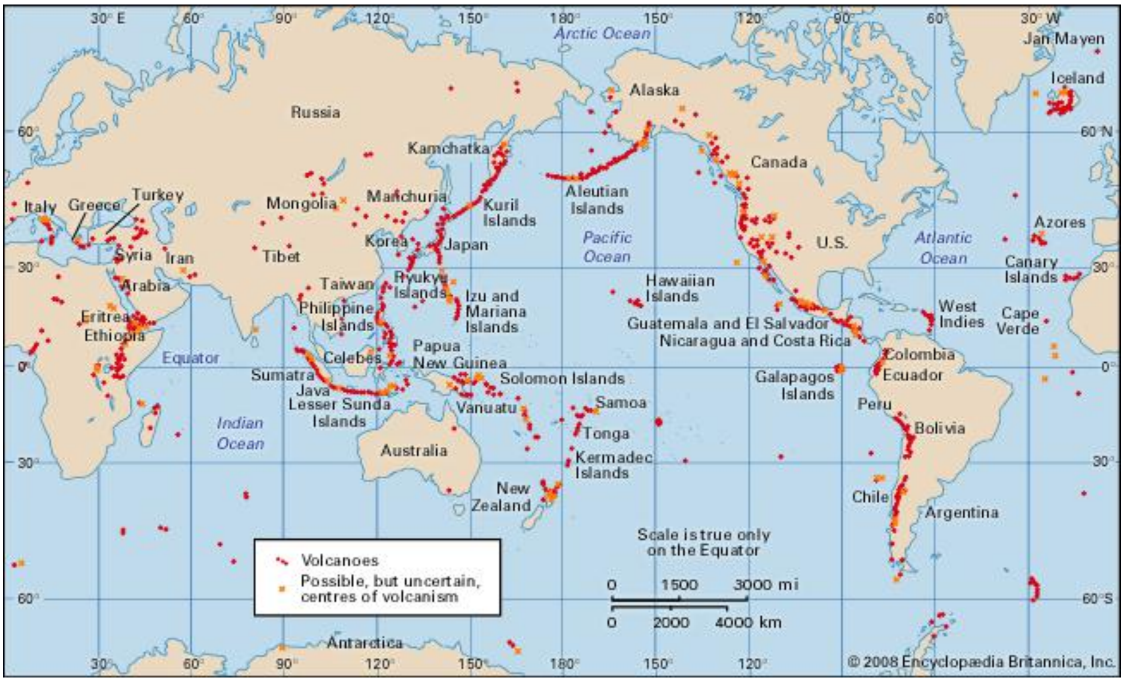


Figure 9: Distribution of volcanoes

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.

4. UPSC Previous Years Prelims Questions

1. The 2004 Tsunami made people realize that mangroves can serve as a reliable safety hedge against coastal calamities. How do mangroves function as a safety hedge? (2011)
- (a) The mangrove swamps separate the human settlements from the sea by a wide zone in which people neither live not venture out
- (b) The mangroves provide both food and medicines which people are in need of after any natural disaster.
- (c) The mangrove trees are tall with dense canopies and serve as an excellent shelter during a cyclone or tsunami
- (d) The mangrove trees do not get uprooted by storms and tides because of their extensive roots

2. In the South Atlantic and South-Eastern Pacific regions in tropical latitudes, cyclone does not originate. What is the reason? (2015)
- (a) Sea surface temperatures are low
- (b) Inter-tropical Convergence Zone seldom occurs
- (c) Coriolis force is too weak
- (d) Absence of land in those regions

5. Previous Years UPSC Mains Questions

1. Explain the formation of thousands of islands in Indonesian and Philippines archipelagos. (2014)

6. Previous Years Vision IAS Test Series Questions

1. What is volcanicity? What are its endogenetic and exogenetic components? Give an account of classification of volcanoes based on mode and periodicity of eruption.

Approach:

- Specific and clear answers should be there for each part of the question.
- Giving examples in classification of volcanoes will make answer more comprehensive.

Student Notes:

Student Notes:

Answer:

- Vulcanicity includes all those processes in which molten rock material or magma rises to the crust to solidify as crystalline or semi-crystalline rocks. 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.
- There is a wide variation in the mode of volcanic eruption and their periodicity. Accordingly the volcanoes can be classified on these bases.
- **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.
  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.
- **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. Shiprock in Netherlands is one such example.

2. Elaborate on the measures that can be taken to mitigate the effect of tsunamis. What global mechanisms are in place for providing early warning related to tsunamis? What are the different technologies used for detecting the presence of tsunami waves?

Approach:

Answer should be general and global in its approach and not India or a particular region specific.

Answer:

- Tsunamis are an ever-present threat to lives and property along the coasts of most of the world's oceans. With the increasing knowledge about generation and propagation of tsunami waves, many mitigation measures are available which can be helpful in reducing the disastrous impact of tsunamis. Some such mechanisms are:
- Advances in tsunami **forecasting** can profoundly influence the development of mitigation strategies. Tsunami hazard assessment include the frequency of

occurrence, the extent, forces, and duration of flooding, the impact of flooding on structures, facilities and infrastructure, and an assessment of the use of the potentially affected coastal areas

- **Natural barriers** can be very effective in mitigating 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.
- Major tsunami warning centres are:
  1. **Pacific Tsunami Warning Center** (PTWC): 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. ITEWS also provide tsunami advisories to the Indian Ocean rim countries along with Australia and Indonesia.
- In order to confirm whether an 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. 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 can provide advance warning to coastal areas that will be first impacted by a tsunami, before the waves reach them and nearby tide gages. Open Ocean buoys often provide a better forecast of the tsunami strength than tide gages at distant locations.

3. Why do earthquake waves develop shadow zones? Also explain the significance of such zones in providing information about the interior of the earth.

Approach:

Describe the concept of shadow zone. Do not elaborate on characteristics of seismic waves, only describe those characteristics which explain development of shadow zone and through light on earth's interior.

Answer:

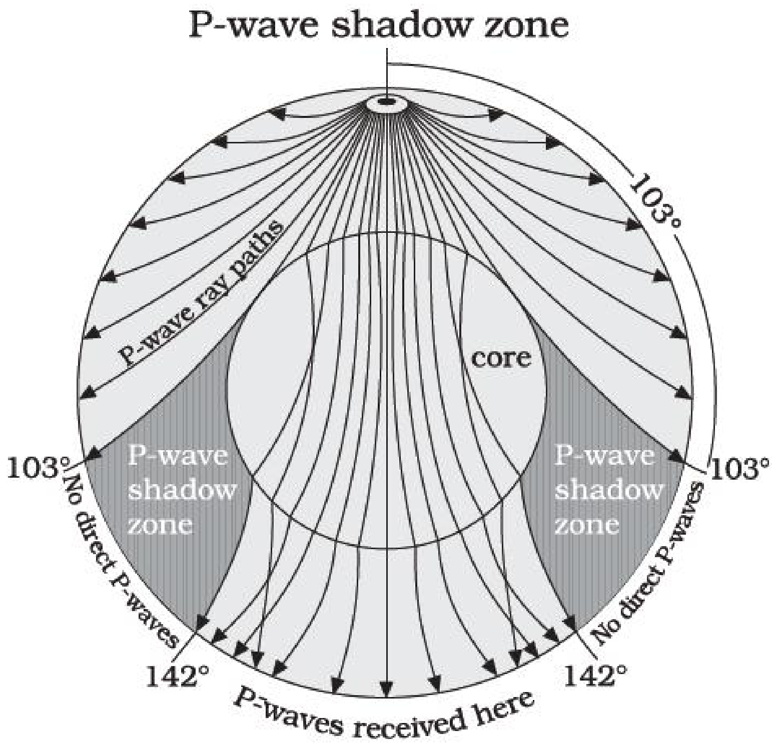
Earthquake waves get recorded in seismographs located at far off locations. However, there exist some specific areas where the waves are not reported. Such a zone is called the 'shadow zone'. The study of different events reveals that for each earthquake, there exists an altogether different shadow zone.

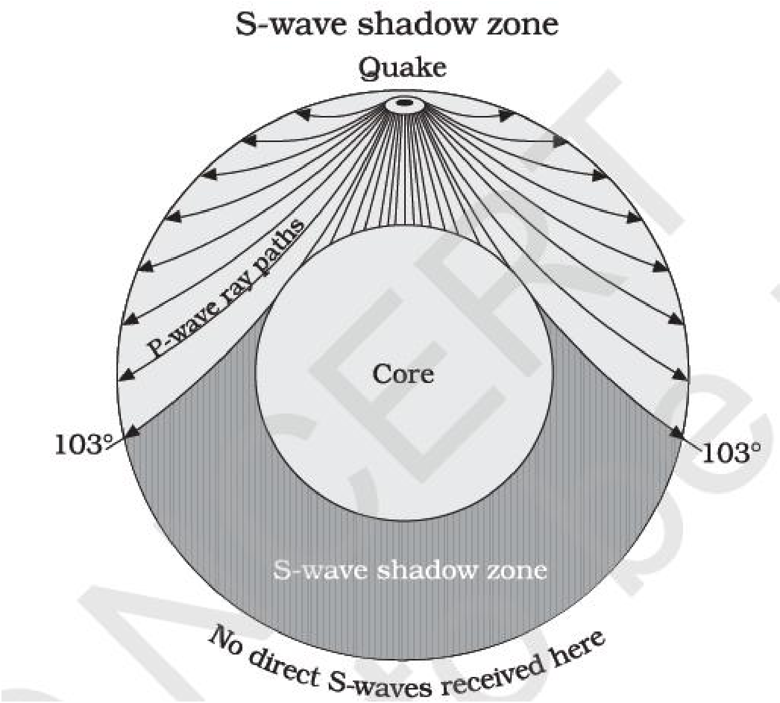
It is observed that seismographs located at any distance within 105° from the epicentre, recorded the arrival of both P and S-waves. However, the seismographs located beyond 145° from epicentre, record the arrival of P-waves, but not that of S-waves.

The entire zone beyond 105° does not receive S-waves. The shadow zone of S-wave is much larger than that of the P-waves. The shadow zone of P-waves appears as a band around the earth between 105° and 145° away from the epicentre. The shadow zone of

Student Notes:

S-waves is not only larger in extent but it is also a little over 40 per cent of the earth surface.





Most of the knowledge we have about Earth's deep interior comes from the fact that seismic waves penetrate the Earth and are recorded on the other side. P and S waves travel **very differently** through the Earth. Initially P and S waves travel in all directions from the epicentre of an earthquake outwards. They are refracted as they travel from the epicentre and follow arcs. However, S waves **cannot** travel through the liquid outer core of the Earth. It was determined that the seismic shadow zones were caused by the inability of S-waves to pass through liquids. This proved to scientists that the interior of the Earth, must contain a layer of liquid material.

Student Notes:

The P-waves were recorded at most seismographs because they have the ability to pass through both solid and liquid layers, but refraction caused them to 'bend' away from areas between 100 and 150 degrees away from the epicentre. By finding the angles at which the P and S waves **both** disappear we can calculate the radius of the liquid core of the earth.

Student Notes:

4. ***Describe the different types of earthquake waves and their modes of propagation. How do the earthquakes occurring in the Fold Mountain regions differ from those occurring at large reservoirs/dams? What is the difference between Shallow-focus and deep-focus earthquakes?***

Approach:

There are three parts of the question as following:

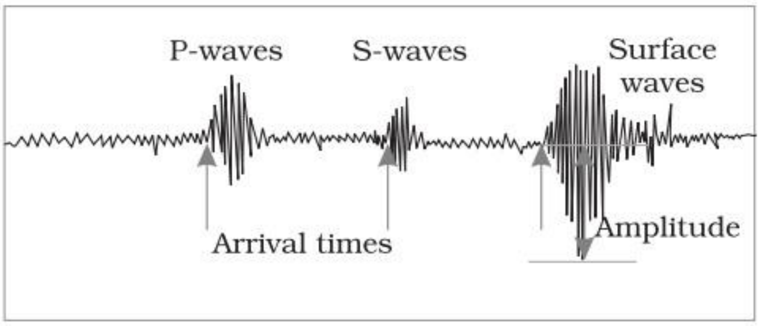
- Types of earthquake waves – body and surface waves. Give some points on their properties in brief with focus on the mode of propagation.
- Earthquakes in fold mountain and reservoir regions – forces for the displacement of rocks differ.
- Difference in Shallow and deep earthquakes – reasons, relation with major and minor earthquakes

Answer:

Earthquake waves are of two types — **body waves** and **surface waves**. Body waves are generated due to the release of energy at the focus and move in all directions travelling through the body of the earth. Body waves are of two types – namely, P-waves and S-waves.

The body waves interact with the surface rocks and generate new set of waves called surface waves. Surface waves move along the surface. The velocity of waves changes as they travel through materials with different densities. Their direction also changes as they reflect or refract when coming across materials with different densities. Surface waves are also of two types -namely, Love and Rayleigh waves.

P-waves can travel through all the mediums while S-waves can travel through only solid. The shadow zone of p-waves is 105-145 degree and that of s-waves is beyond 105 degree.



Different types of earthquake waves travel in different manners. P-waves vibrate parallel to the direction of the wave. This creates density differential within the material. S-waves and Surface waves vibrate perpendicular to the direction of propagation. Hence, they create troughs and crests in the material. This makes the Surface waves the most damaging earthquake waves.

Earthquakes in the **Fold Mountain regions** are the most common type of earthquake while large **reservoir induced earthquakes (RIE)** is a rare phenomenon. The earth's crust breaks due to collision of tectonic plates in the Fold Mountain regions that cause vibrations. The most widely accepted explanation of RIE is related to the extra water pressure created in the micro-cracks and fissures in the ground. RIE is not well established. Reservoirs can both increase the frequency of earthquake in the high seismic areas and cause earthquake to happen in less seismic areas.

Student Notes:

The focus/hypocentre is the point inside earth where energy is released during an earthquake. **Shallow-focus earthquakes** are above 70km depth and deep-focus one in the range of 70-700km depth. **Deep-focus earthquakes** are localized within great slabs of shallow lithosphere that are sinking into the Earth's mantle. A large earthquake has a deep focus is the small amplitude of the surface-waves. The hypocentre of RIE is relatively at less depth.

5. What are Tsunamigenic zones? Give examples of such zones in the vicinity of Indian Coastal regions. Examine the preparedness level of India to minimize the impact of Tsunamis.

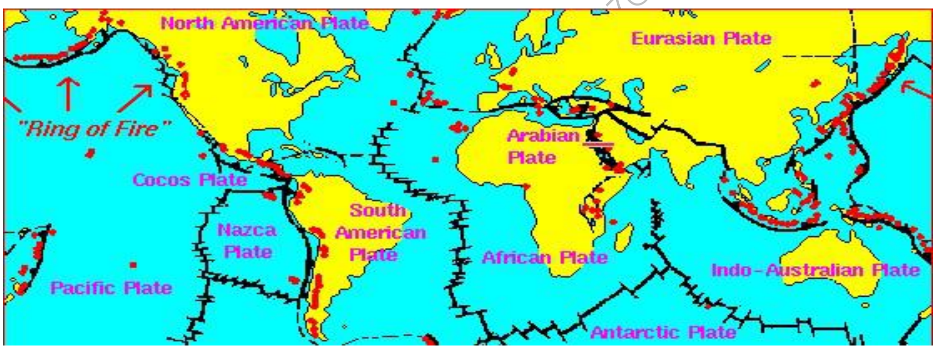
Approach:

There are three parts of the question as follows:

- Tsunamigenic zones – earthquake zones commonly along major subduction zone plate boundaries that can generate Tsunamis
- Mention zones along with their approximate distances from mainland and islands of India.
- Assess the Preparedness level in today's time. Focus on the steps taken after 2004 Tsunami. Talk about the issues in the present system.
- Conclusion – final statement on preparedness and then can suggest some measures in a line or two.

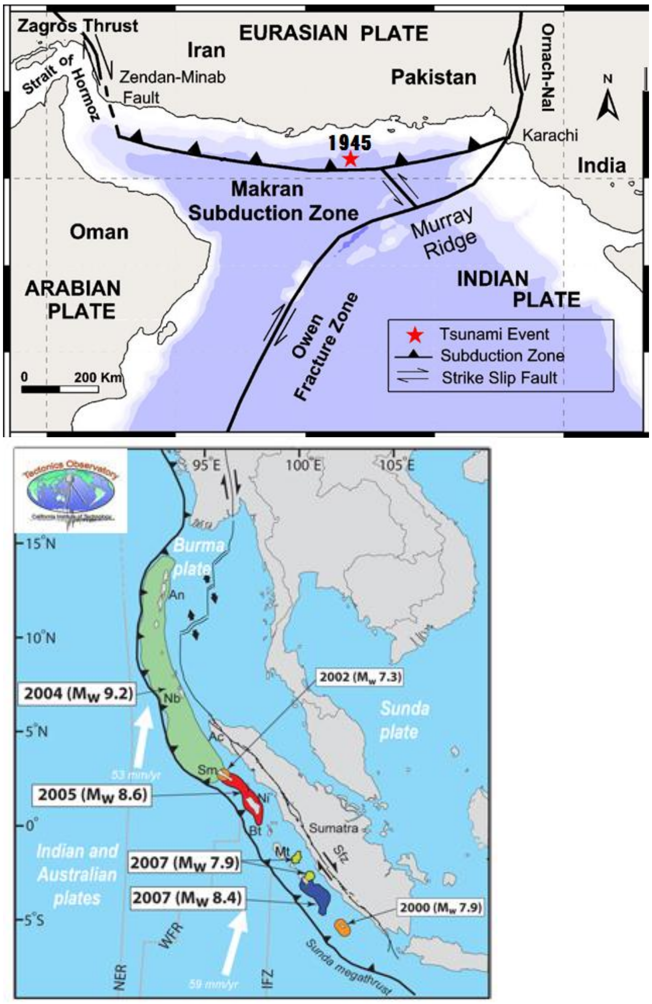
Answer:

Tsunamigenic zones are the regions in the sea where vertical shifting of water mass can cause Tsunami waves. Tsunami can be created by earthquakes and volcanoes etc. Region of convergent tectonic plate boundaries are the most likely sources for Tsunami. Therefore, these zones are not randomly distributed as shown in the map below.



Tsunamigenic zones along the converging plate boundaries in the sea regions

Two main Indian Ocean Tsunamigenic zones are Makran subduction zone (MSZ) in the Northern Arabian Sea and Indonesian subduction zone (ISZ) in the Bay of Bengal near Indonesian Islands. These zones are result of the active tectonic collision process that is taking place along the southern boundary of the Eurasian plate as it collides with the India plate and adjacent micro-plates. MSZ is not far from India's coast and a major earthquake can be disastrous for India. 2004 Tsunami was generated in the ISZ, which is very near to the Andaman and Nicobar Islands and about 1300km from the mainland India.



Makran subduction zone and Indonesian subduction zone

India had some lessons to learn from the Tsunami of 2004. Government installed "Indian Tsunami early warning system" was developed which is integrated with the system of other Asian countries. It has a network of seismometers, tidal gauges and ocean buoys.

Other measures include mapping of vulnerable coastal areas, awareness and community preparedness activities. Yet critical gaps remain. While the system can send out warnings quickly, dissemination of the alerts to people on the ground takes time. Coastal infrastructure is still poor.

Tribes of A&N Islands moved to higher places in the interiors in advance with the help of tradition knowledge during the Tsunami of 2004. There is a need to integrate such knowledge in the system. Mangroves require special attention from government. Only a very handful of scientists are working on Tsunami research today.

6. ***Explain the phenomenon of Tsunami formation and highlight reasons for India's vulnerability to Tsunamis. List some measures to mitigate the impact of Tsunamis.***

Approach:

- Explain the phenomenon of Tsunami formation through earthquakes, etc.
- Illustrate the location of subduction zones to highlight India's vulnerability.
- Provide measure to mitigate impact of Tsunamis

Student Notes:

Student Notes:

Answer:

A tsunami is a large destructive oceanic wave that can be generated by any disturbance that rapidly displaces a large mass of water, such as an earthquake, volcanic eruption, and landslide or meteorite impact. Tsunamis are fast moving waves which have small amplitude in the deeper parts of the ocean. As they approach the coast, waves slow down due to friction from the floor and those coming from behind pile up on them. This raises the wave height, which can go as high as 15-20m when Tsunami strikes.

Formation of Tsunamis:

- Undersea earthquake:
  EQs are the most common cause Tsunami. Undersea earthquakes occurring at depth less than 50km with the epicentre or fault line near or on the ocean floor cause rapid movements of ocean basins.
  Eg: when the two converging lithospheric plates come close, the heavier plate is thrust under the lighter plate and displacement of the crust takes place at the subduction zone giving rise to tsunamis.
- Landslides:
  Landslides like rock falls or icefalls or underwater landslides also can result into vertical displacement of sea water and result into generation of tsunami waves.
  Eg : Construction work of an airport runway along the coast of southern France in 1980.
- Volcanic eruptions:
  Either due to sudden volcanic eruptions or due to collapse of volcanic roofs, massive displacement of water may take place, which can cause a Tsunami.
- Meteorites and asteroids hitting the seas also generate violent waves that can cause Tsunamis.
  Tsunamis occur frequently in areas of plate subduction, such as the Pacific rim, Indonesian Archipelago etc.

India's vulnerability to Tsunamis

- The Indian-Australian plate is breaking and frequent violent movements near the Indonesian archipelago cause massive earthquakes and Tsunamis (E.g. in 2004)
- Long coastline and high population density along the coasts
- Poor disaster-proof infrastructure which abets vulnerability
- Disaster Risk Reduction system still in its nascent stage

Mitigation measures

- Mapping the vulnerable areas for level of risk upto village level.
- Development of Disaster Information Management System (DIMS) in all the coastal states.
- Advance warning about tsunamis like the Indian Ocean Advance Warning System, which involves number of vulnerable Indian Ocean littoral countries.
- Mangrove forests on coasts act as an efficient barrier.
- Structural protection such as sea walls, break-waters, bio-shields.
- Control of sea mining: E.g. Mining of sand and other minerals from the sea, as is done in Kanyakumari, makes the concerned area highly vulnerable to tsunamis. The sand deposited on the sea floor absorbs much energy of the waves.
- Awareness generation and training among the fishermen, coast guards, officials from fisheries department and port authorities and local district officials etc., in connection with evacuation and post tsunami storm surge management activities. Regular drills should be conducted to test the efficacy of the DM plans.

7. ***The composition of lava materials determines the types of volcanoes. Illustrate. Also give an account of intrusive landforms formation due to volcanic activities.***

Student Notes:

Approach:

- Give brief detail of constituents of lava material and explain how these constituents affect the characteristics of moving magma.
- Illustrate with example how these constituent determine different types of volcanoes.
- Give a detailed account of intrusive landforms formation due to volcanic activities.

Answer:

The major constituent of the ejected material from volcanism is molten magma. It is generally classified into two categories based on the compositional share of silica.

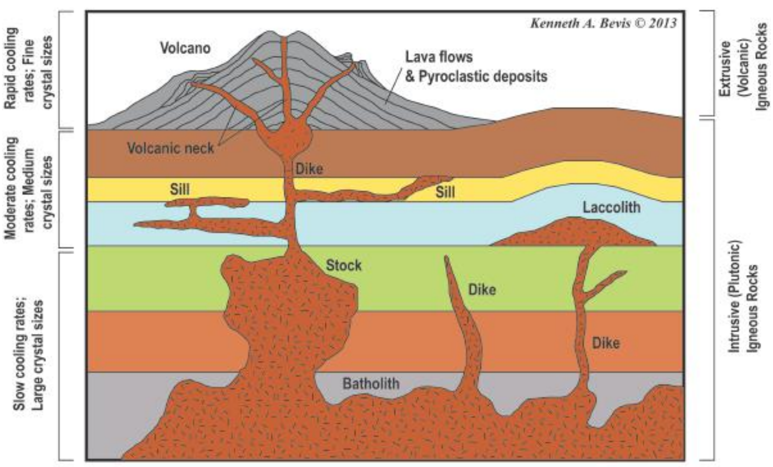
1. **Basic magma** or basaltic lava which is less in silica and in accordance is mobile magma type. Eruptions of basaltic lava are usually quiet.
2. **Acidic magma** or andesitic lava with higher silica content forms the viscous magma developing early solidification. It is usually accompanied by violent eruptions.

The gaseous constituent of ejected matters relates to the intensity of ejection. Since the type of volcanoes formed entirely depends upon the way lava gets ejected through the vent, the composition of lava material plays predominant role.

- **Shield Volcanoes-** These volcanoes are mostly made up of basaltic lava which is very fluid when erupted, thus making these volcanoes less steep. Hawaiian volcanoes are the most famous examples.
- **Composite volcanoes-** They are formed when lava is more viscous, cooler and consists of large quantities of pyroclastic materials and ashes. It accumulates in the vicinity of the vent openings leading to formation of layers.
- **Caldera-** These are usually so explosive owing to trapped gasses that when they erupt they tend to collapse on themselves rather than building any tall structure.
- **Flood Basalt Provinces-** These volcanoes outpour highly fluid lava that flows for long distance forming sheets of lava. Deccan trap is prominent example.

Intrusive Volcanic landforms- The lava that cools in the crust itself is also called as plutonic rocks and they assume different forms. These forms are called intrusive forms. Some of them are-

- **Batholiths**- These are the large domes formed by the cooling of a large body of magmatic material at the deeper depth of the crust. They cover large areas, and at times, assume depth that may be several kms.
- **Lacoliths**- These are large dome-shaped intrusive bodies with a level base and connected by a pipe-like conduit from below and are located at deeper depth.
- **Lapolith, Phacolith and sills**- While moving upwards, a portion of the lava may tend to move in a horizontal direction wherever it finds a weak plane. In case it develops into a saucer



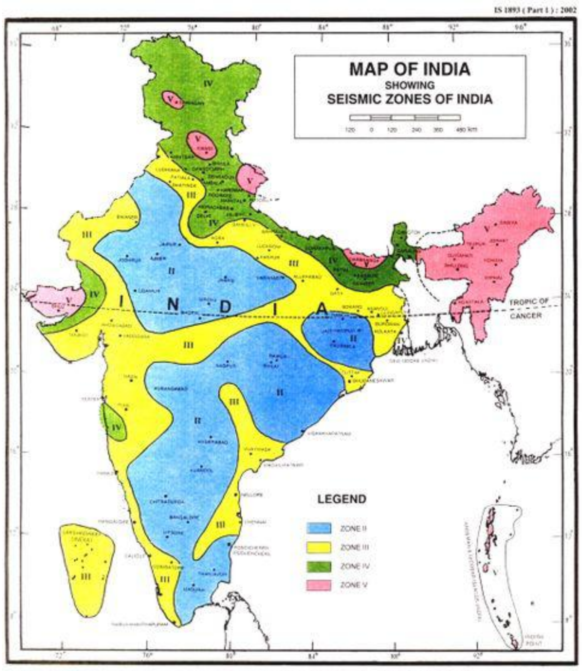
shape, concave to the sky body, it is called lapolith. A wavy mass of intrusive form are phacoliths. The near horizontal bodies of the intrusive igneous rocks are called sill.

- **Dykes-** When lava makes its way through cracks and the fissures developed in the land. It solidifies almost perpendicular to the ground. It gets cooled to develop a wall-like structure called dykes.

8. ***Give an account of the different types of earthquakes based on their zone of occurrence. Identify the earthquake prone regions of the world with special reference to India. Also explain the reasons for the occurrence of earthquakes in geologically inactive regions like Peninsular India.***

Approach:

- Briefly explain earthquakes and mention the required classification. Also write about the intensity difference.
- Elaborate their distribution. Identify the prominent belts which are earthquake prone.
- In the last part, examine why earthquakes occur in stable peninsular block. Use examples wherever possible.

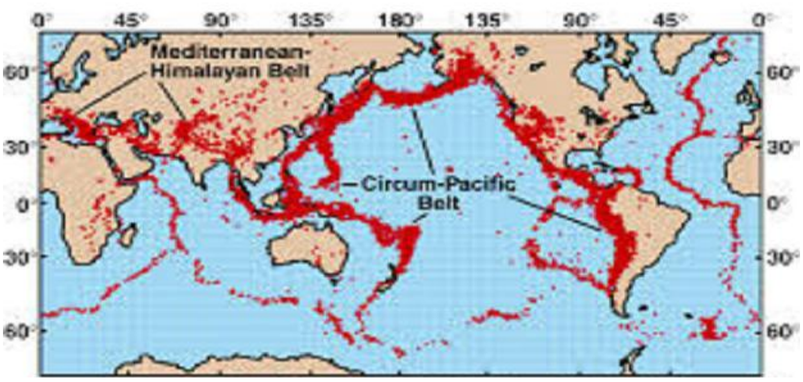


Answer:

Earthquakes are sudden shaking of ground caused by passage of seismic waves through earth rocks. These waves are produced when some form of energy stored in earth's crust is suddenly released.

There are many ways of classifying earthquakes. However, based on their zone of occurrence or origin inside the earth, they can be classified as follows:

Shallow earthquakes: Most parts of world experience at least occasional shallow earthquakes-those that originate within 60 km of Earth's outer surface. In fact, great majority of earthquake foci are shallow. They are caused along the constructive plate boundaries (mid-oceanic ridges) and are generally of lesser magnitude.



Intermediate earthquakes: These are earthquakes with a focal depth ranging from about 60 to 300 km.

Student Notes:

Student Notes:

Deep Focus: Frequency of occurrence falls off rapidly with increasing focal depth in intermediate range. These are of high magnitude and are caused along the convergent or destructive plate boundaries and consequent subduction along the Benioff zone.

In the world, the earthquake distribution is depicted in the following map:

About 68 per cent of all earthquakes are observed in the vast regions of the **Pacific ocean** as a '**ring of fire**' and is closely linked with the region of crustal dislocations and volcanic phenomenon.

Around 21 per cent of them occur in the **Mid-world mountain belt** extending parallel to the equator across the Mediterranean sea from Alpine-Caucasus range to the Caspian, Himalayan mountains and the adjoining lands. The region has fold mountains and large depressions.

The remaining 11 per cent are recorded outside these two belts.

The **earthquakes in India** are mainly confined to the Himalayan region and its foothills. Based on the past seismic history, country is divided into **four seismic zones**, viz. Zone-II, -III, -IV and –V. Of these, Zone V is the most seismically active region, while zone II is the least.

Earthquakes in Peninsular India

While the plate boundary region in and around Himalayas are prone to earthquakes because of energy generated due to collision of plates. However, even peninsular India is prone to some devastating earthquakes. The reasons include-

- It is possible that collision of Indian and Eurasian plate has generated stresses not only at boundaries but also inside plate. As a result zones of weakness have formed on the plate.
- There is possible breaking up of Indian plate, which is most evident along river Bhima near Latur and Osmanabad, regions experiencing disturbances in the past.
- Also, this region is home to some grand dams and reservoirs which have resulted in reservoir induced earthquakes (eg. Koyna Dam).

9. Explain the reasons behind earthquakes in Himalayas being more intense and frequent than the ones occurring in Alps region. Why are scientists predicting a largescale earthquake in northern India? Also, elaborate upon some prominent earthquake forecasting techniques.

Approach:

- Explain the reasons behind earthquakes in Himalayas being more intense and frequent than the ones occurring in Alps region.
- State the reasons for scientists predicting a large-scale earthquake in northern India.
- Elaborate upon some prominent earthquake forecasting techniques

Answer:

Earthquakes are on-ground manifestation of energy released during shattering and movement of crustal plates. The amount of energy released depends up on the depth of earthquake and the intensity of collision of plates. In regions of ongoing and faster movement of plates, earthquakes are more frequent.

Himalayas are relatively younger fold mountains than Alps. Also, the Indian plate's movement toward the eurasian plate is occuring at a relatively faster pace. Since the rocks in this region have not stabalised, they are brittle and shatter frequently. This is the reason why there are more intense and frequent earthquakes in Himalayas than the Alps, where the plates converge slowly, and hence, there is less seismic activity.

Reason behind prediction of a largescale earthquake in northern India

The frontal thrust in the central Himalayas (covering parts of India and eastern Nepal) has remained seismically quiet for 600 to 700 years. This implies an enormous build-up of strain in the region. This stacking up of strain in the region may cause at least one earthquake of magnitude 8.5 or more in one of the overlapping segments of the central Himalayas anytime in the future.

Forecasting can play an important role in earthquake disaster mitigation. Some of them are as under:

- **Observation based:** Unusual animal behavior such as restlessness and movement have been observed. However, their correlation with earthquakes is not yet established.
- **Hydrochemical precursors:** Dissolved concentration of minerals has been observed to change during days preceding earthquake. Release of radon gas is also observed.
- **Seismic gap:** Scientists predict earthquake based on expected build-up of strain in regions where earthquakes are expected but have not happened in sometime.
- **Statistical models:** A combination of classical earthquake statistics and numerical models such as seismo-thermo-mechanical (STM) modelling that simulates the way the tectonic plates move and collide.
- **Physics based models:** Recently a research, conducted by Columbia University, simulated nearly 500,000 years of California earthquakes on a supercomputer, which was able to match hazard estimates based on statistical models.
- **Uniform California Earthquake Rupture Forecast (UCERF3)**: It provides authoritative estimates of the likelihood and severity of potentially damaging earthquake ruptures in the long- and near-term.
- **Technological interventions:** Local geology and structural maps published by GSI, Google Earth imagery from ISROs, Carto-sat 1 contributes to research and development
- **Palaeoseismology:** Geological Investigations of active faults.
- Other methods of **traditional prediction** include unusual animal behaviour, change in underground water, Radon gas levels in soils etc.

Student Notes:

MOUNTAIN BUILDING ISLAND FORMATIONS AND HOTSPOTS

Student Notes:

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'.

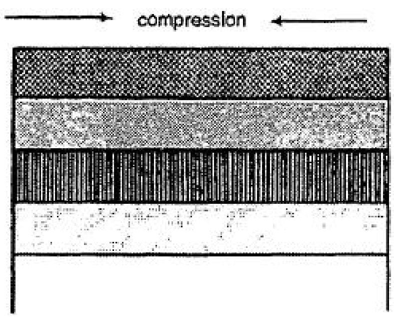


Fig.1 Earth's crust before folding

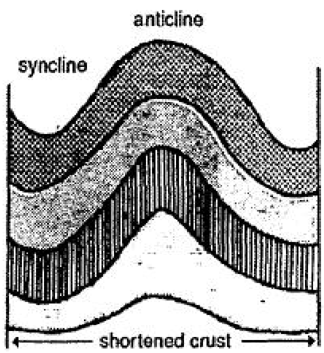


Fig.2 Earth's crust after folding

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*.

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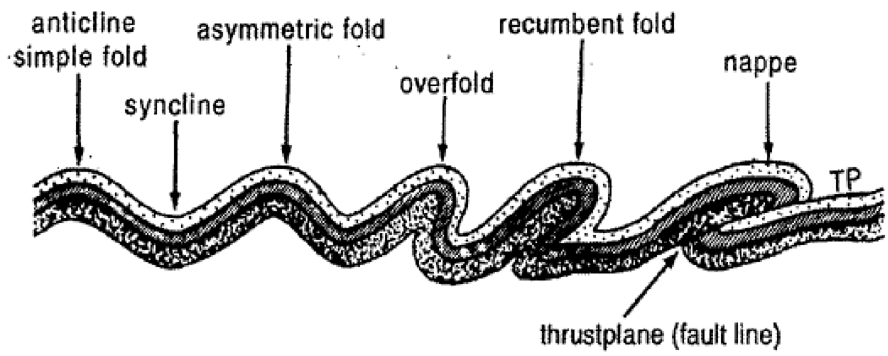


Fig. 3 Types of Folding

Student Notes:

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.

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.

Student Notes:

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.

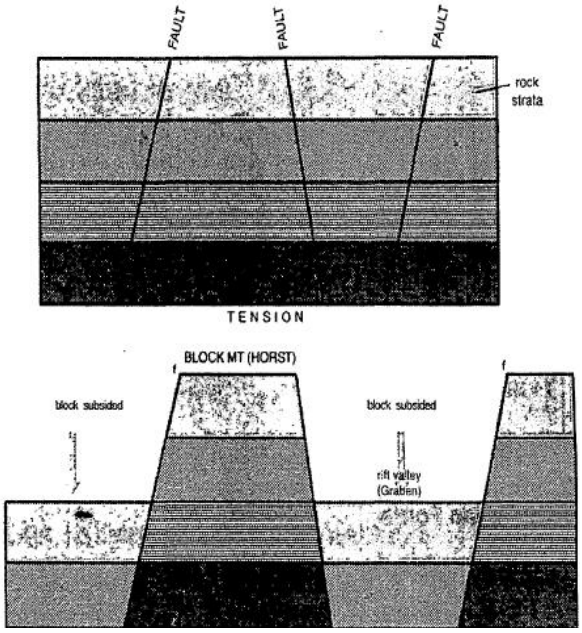


Fig. 4 Block Mountains formed by tensional forces

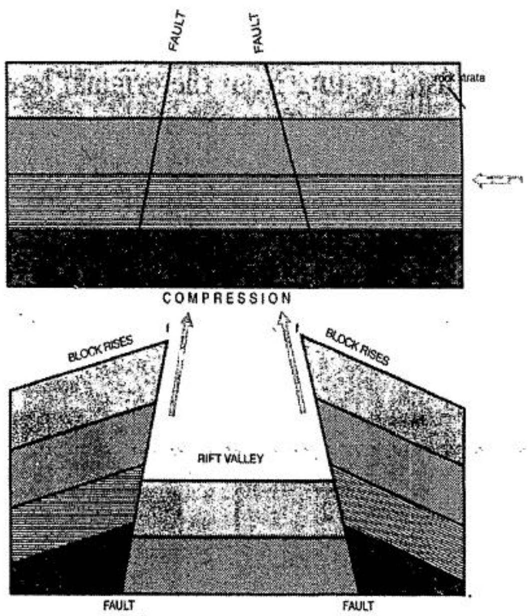


Fig.5 Rift Valley formed by compressive forces

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).

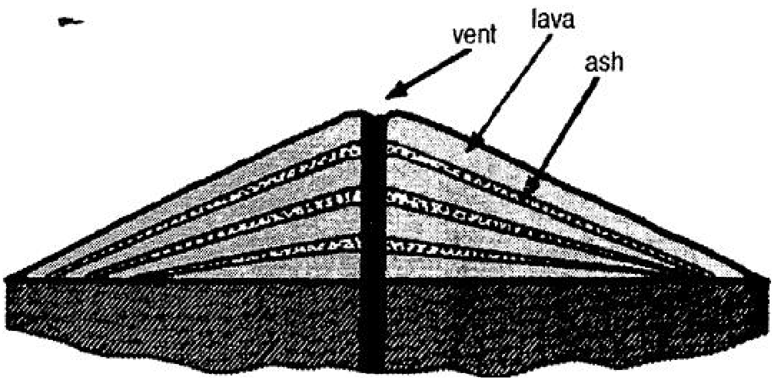


Fig. 6 Volcanic Mountains

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.

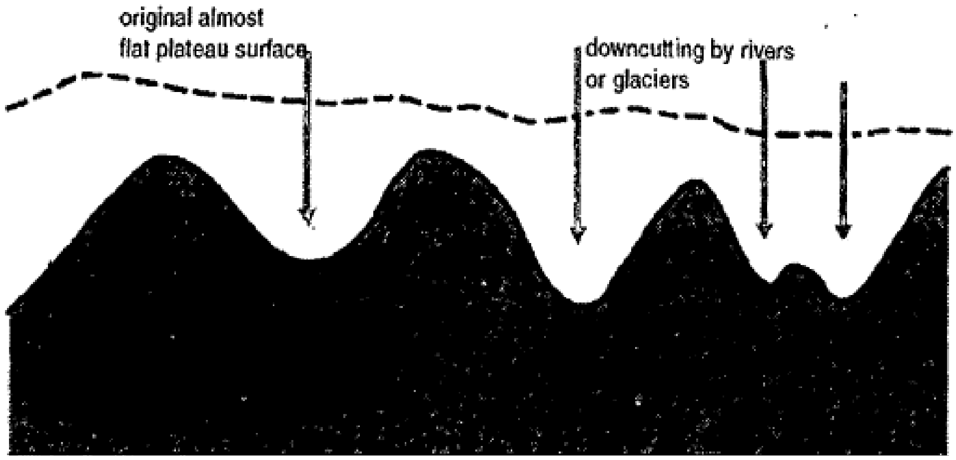


Fig. 7 Residual Mountains

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:

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, Ryukyuls lands, Kurile Islands and other island arcs of the Pacific coasts.

Student Notes:

2.2. Oceanic Islands

Student Notes:

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.

Artificial Island

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

[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:

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:

4. Previous Years UPSC Prelims Questions

1. When you travel in Himalayas, you will see the following:
1. Deep gorges
2. U-turn river courses
3. Parallel mountain ranges
4. Steep gradients causing land-sliding.

Which of the above can be said to be the evidence for Himalayas being young fold mountains? (2012)

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

5. Previous Years UPSC Mains Questions

1. Bring out the causes for more frequent occurrence of landslides in the Himalayas than in the Western Ghats. (2013)
2. Why are the world's fold mountain systems located along the margins of continents? Bring out the association between the global distribution of fold mountains and the earthquakes and volcanoes. (2013)
3. "The Himalayas are highly prone to landslides. Discuss the causes and suggest suitable measures of mitigation. (2015)

6. Previous Years Vision IAS Test Series Questions

1. Explain the differences between fold and block mountains, with examples.

Approach:

- Compare the process of formation of both the mountain types.
- Compare the characteristic features – size, elevation of both the mountain types.
- Provide examples.

Answer:

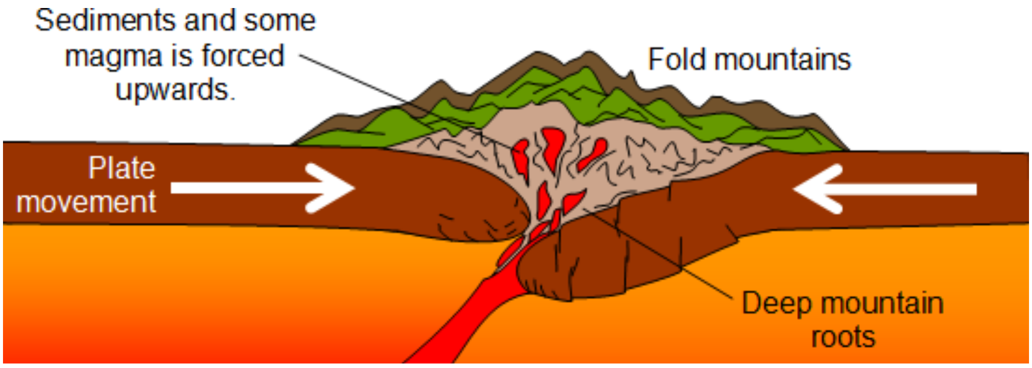
The Block and the Fold mountains, although are both uplifted physical features, yet from their formation to their later life, they are extremely different. These differences can be pointed out as under.

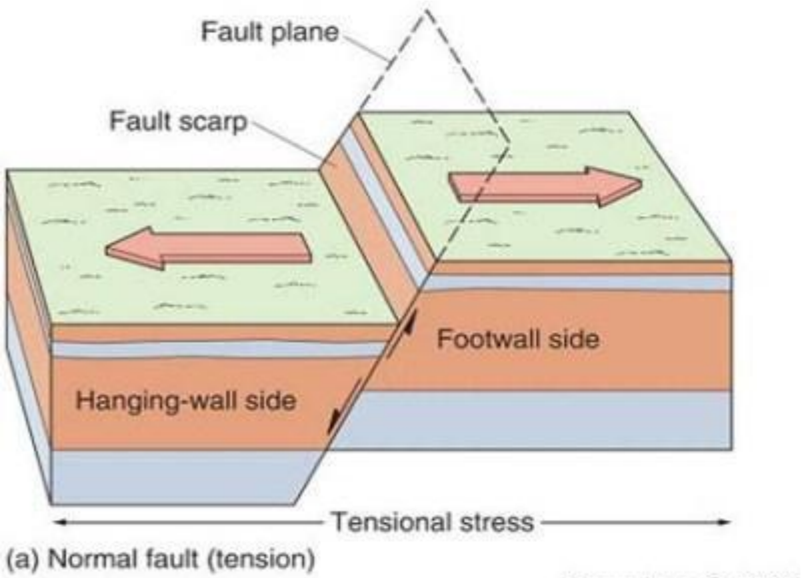
Formation of the mountains:

- **Fold Mountains**: They are produced when tectonic plates move towards each other. The resulting compressive force cause wrinkling or folding along the lines of weakness.
- **Block Mountains:** When the fault develops in the earth's crust by either compressive or tension experienced by it, it uplifts a certain portion of the land leading to formation of the Block Mountain.

Features:

- **Fold mountains**:
  - Very high but gradual elevation mountains.
  - They contain many active volcanoes e.g. around circum- pacific fold mountain system
  - Contain mineral rich resources
- **Block**
  - Comparatively elevation is much lower
  - Leads to formation of steep blocks enclosed by faults, rift valleys.





Student Notes:

Example:

- **Fold**: Most Widespread Mountains found throughout the world. Himalyas in the Central Asia, India and China are examples of it. Rockies in America, Andes in South America and Alps in Europe are examples of it.
- **Block Mountains:** Black forest of Rhineland, Hunsruck Mountains, East African Valley system, and the mountains surrounding the Narmada Rift Valley in India.

ROCKS AND MINERALS

Student Notes:

Contents

1. Introduction

Student Notes:

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.
Amphibole	Aluminum, calcium, silica, iron, magnesium are the	used in asbestos industry Hornblende is another	They form 7 per cent of the

	major elements of amphiboles.	form of amphiboles	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.

Student Notes:

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.

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.

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

Student Notes:

- 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

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.

Student Notes:

4. Rock Cycle

Student Notes:

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.

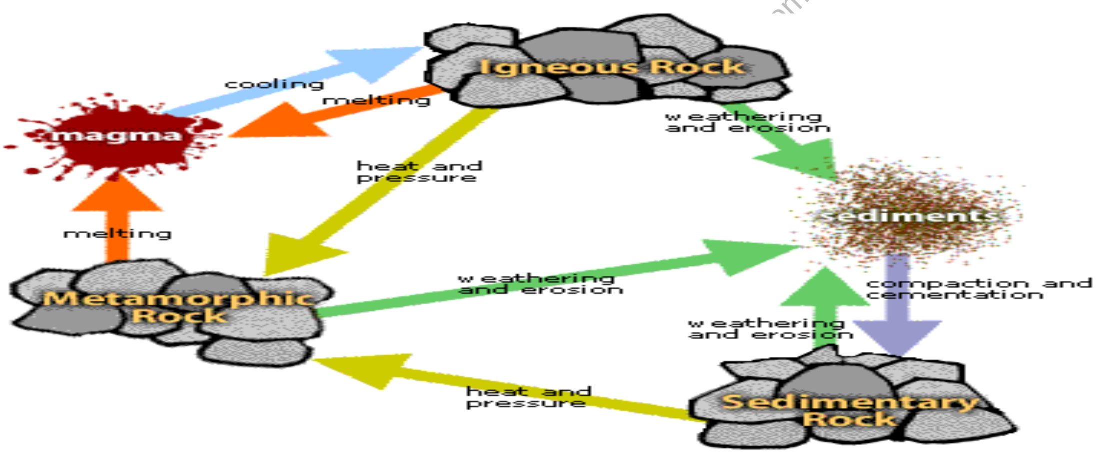
The sedimentary rocks may be buried again and may melt to form the igneous rocks.

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.



5. UPSC Previous Years Prelims Questions

1. Which reference to the mineral resources of India, consider the following pairs:

Mineral		90% Natural sources in
1. Copper	:	Jharkhand
2. Nickel	:	Orissa
3. Tungsten	:	Kerala

Which of the pairs given above is/are correctly matched? (2010)

(a) 1 and 2 only (b) 2 only
(c) 1 and 3 only (d) 1, 2 and 3

Student Notes:

2. Which one of the following is the appropriate reason for considering the Gondwana rocks as most important of rock systems of India? (2010)
(a) More than 90% of limestone reserves of India are found in them
(b) More than 90% of India's coal reserves are found in them
(c) More than 90% of fertile black cotton soils are spread over them
(d) None of the reasons given above is appropriate in this context"

3. In which of the following regions of India are shale gas resources found? (2016)
1. Cambay Basin
2. Cauvery Basin
3. Krishna-Godavari Basin
Select the correct answer using the code given below.
(a) 1 and 2 only (b) 3 only
(c) 2 and 3 only (d) 1, 2 and 3

4. With reference to the management of minor minerals in India, consider the following statements:
1. Sand is a 'minor mineral' according to the prevailing law in the country.
2. State Governments have the power to grant mining leases of minor minerals, but the powers regarding the formation of rules related to the grant of minor minerals lie with the Central Government.
3. State Government have the power to frame rules to prevent illegal mining of minor minerals.
Which of the statements given above is/are correct? (2019)
(a) 1 and 3 only (b) 2 and 3 only
(c) 3 only (d) 1, 2 and 3

5. Consider the following minerals:
1. Bentonite
2. Chromite
3. Kyanite
4. Sillimanite
In India, which of the above is/are officially designated as major minerals? (2020)
(a) 1 and 2 only (b) 4 only
(c) 1 and 3 only (d) 2, 3 and 4 only

6. Previous Years UPSC Mains Questions

1. It is said that India has substantial reserves of shale oil and gas, which can feed the needs of the country for quarter century. However, tapping of the resource does not appear to be high on the agenda. Discuss critically the availability and issues involved. (2013)
2. How does India see its place in the economic space of rising natural resources rich Africa? (2014)

LANDFORMS AND THEIR EVOLUTION

Student Notes:

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

Student Notes:

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

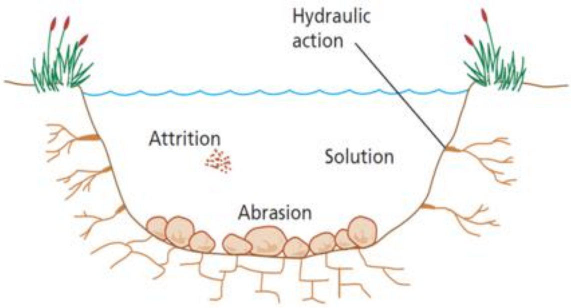
The work of a stream includes erosion, transportation and deposition. These activities go on simultaneously in all stream channels.

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

[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)

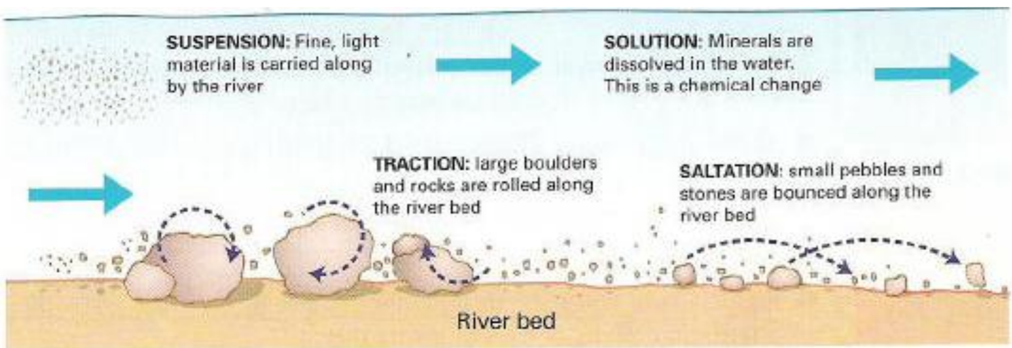
- **Solution or Corrosion-** This is the chemical action of river water. The acids in the water slowly dissolve the bed and the banks. This occurs in streams running through rocks such as chalk and limestone.
- **Abrasion or Corrasion-** As the rock particles bounce, scrape and drag along the bottom 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.



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

Student Notes:

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.

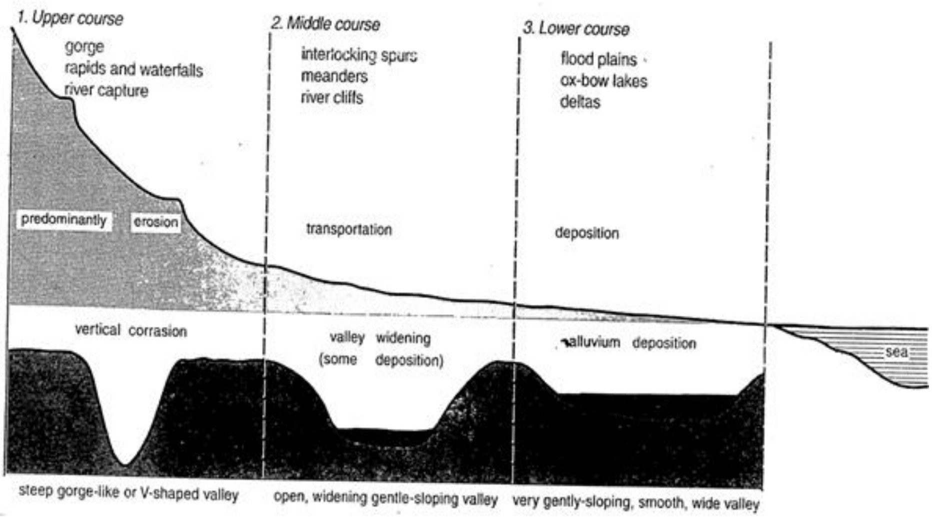
Student Notes:

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:

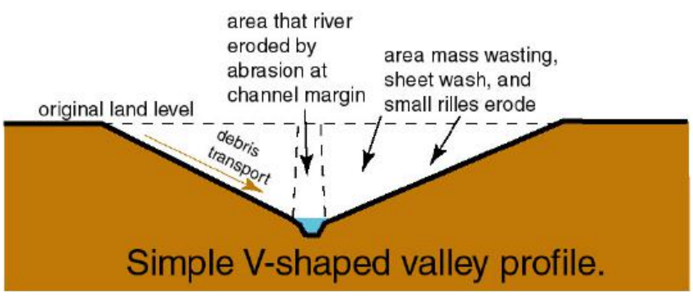
1. The upper course or the stage of youth
2. The middle course or the stage of maturity
3. The lower course or the stage of old age.



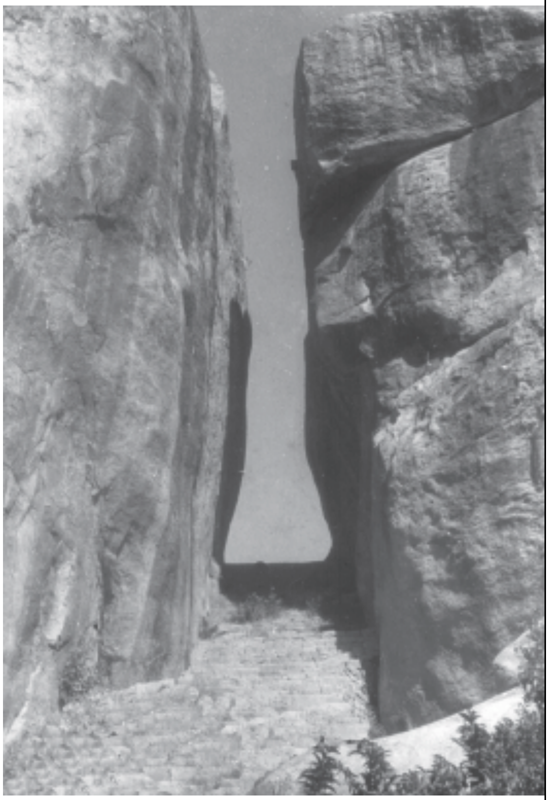
The Upper, Middle and Lower Courses of River

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.

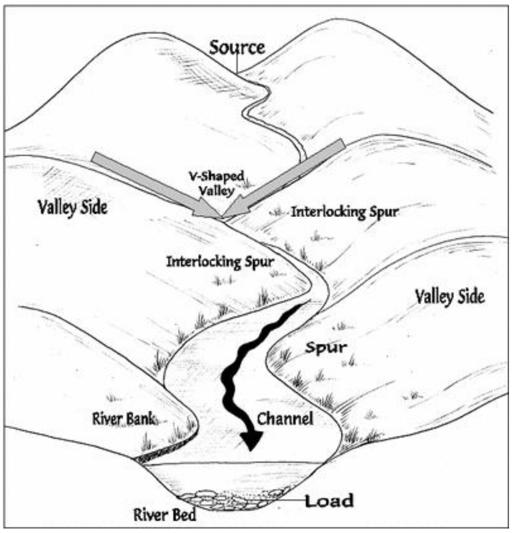


- If the bed rock is hard and resistant, the widening of the valley at its top may not take place and the down cutting process of a vigorous river may lead to the formation of a **gorge** i.e. a river valley with almost vertical sides. George generally develops between pairs of escarpments or cliffs. 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

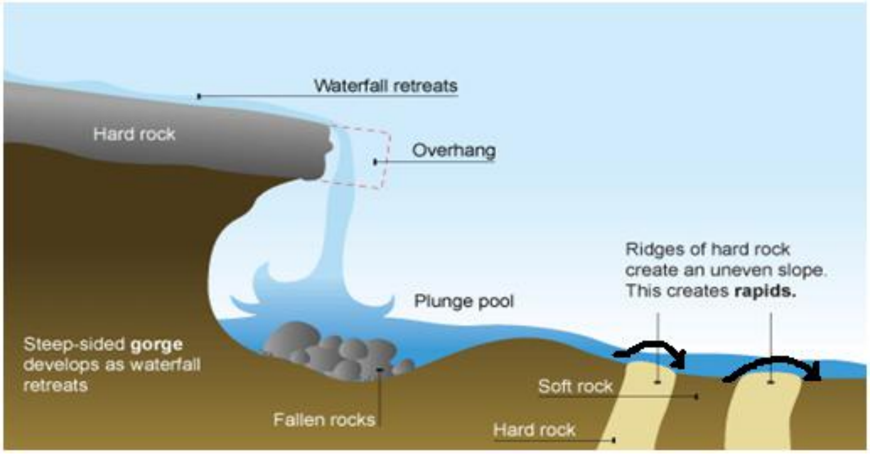
- The narrow and very deep gorge with vertical walls is known as 'I' shaped valley or **canyon**. A canyon is **very deep gorge with steep sides running for hundreds of kilometers**, e.g. Grand Canyon of the river Colorado in U.S.A.
- As the river flows through the valley it is forced to swing from side 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

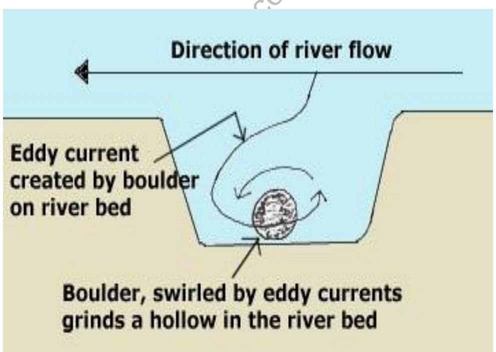
Waterfalls develop when a layer of erosion-resistant rock lies across a streams course. The less resistant rock on the downstream side is more easily eroded than the resistant rock. The river bed is thus steepened where the two rocks meet and a waterfall develops. The great force of falling water in 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.

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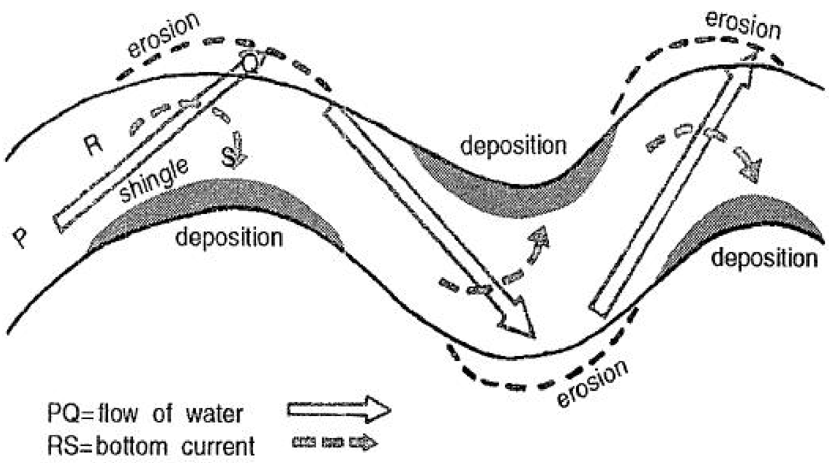
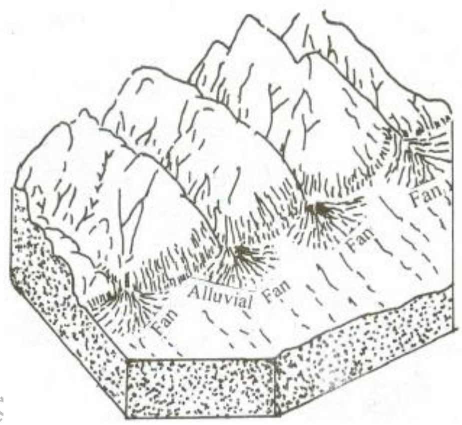


Fig: Development of a meander.

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



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.**

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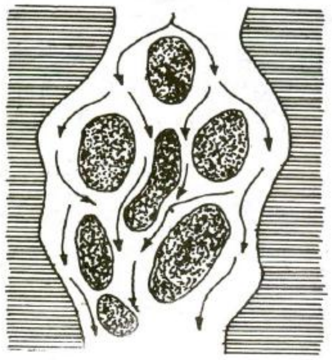
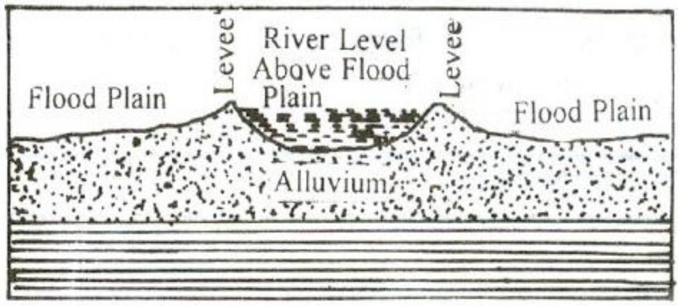


Diagram showing Braided stream



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.

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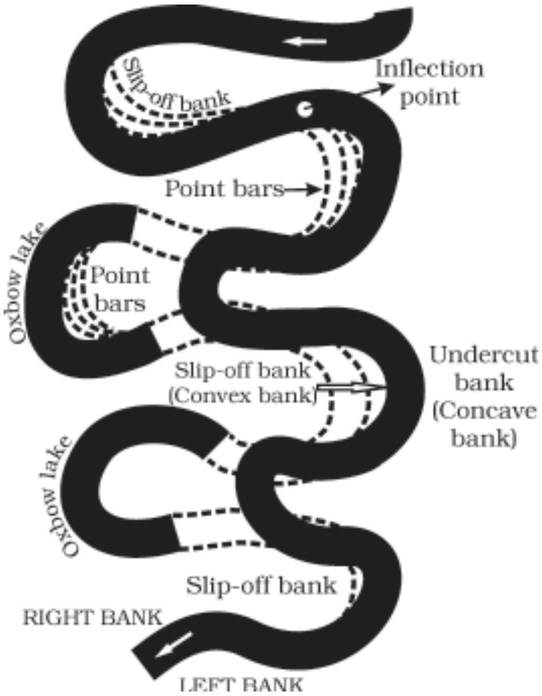
Student Notes:



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**.

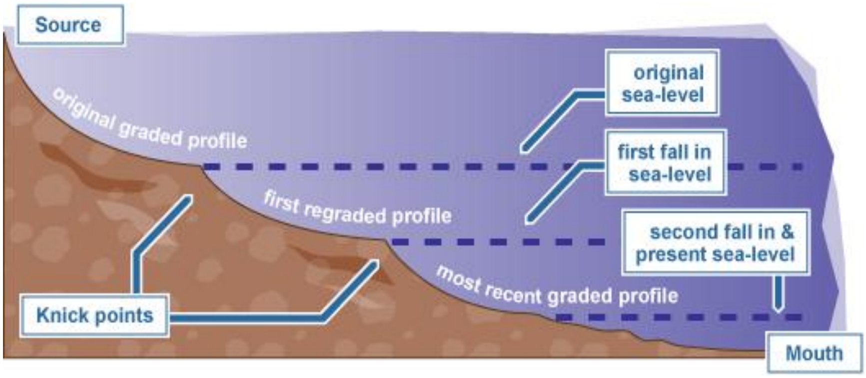
The formation of estuaries is due to the **scouring action of tides and currents**. But in most of the cases the original cause is the subsidence of the earth's crust in the area of the outlet. The two west flowing rivers of India, the Narmada and the Tapi do not form deltas. They form estuaries when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

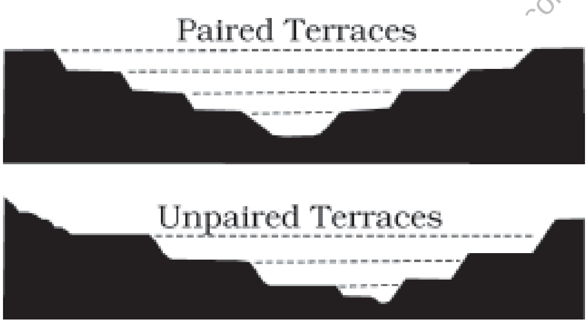


When a river is rejuvenated, adjustment to the new base level starts at the sea and gradually works its way up the river's course. The river gains renewed cutting power (in the form of vertical erosion), which encourages it to adjust its long profile. In this sense the knick point is where the old long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



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.

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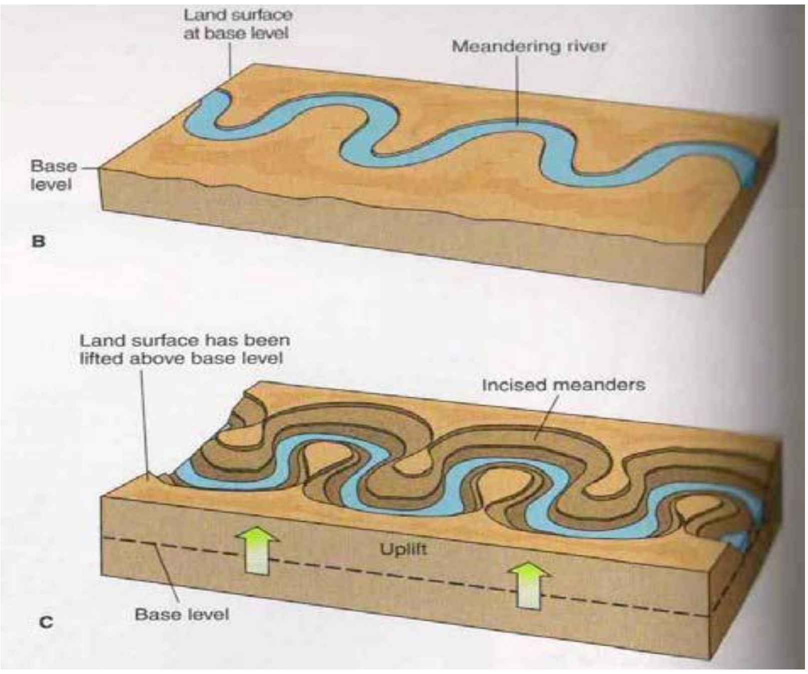


Diagram showing incised meander

Student Notes:

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.

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

Student Notes:

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

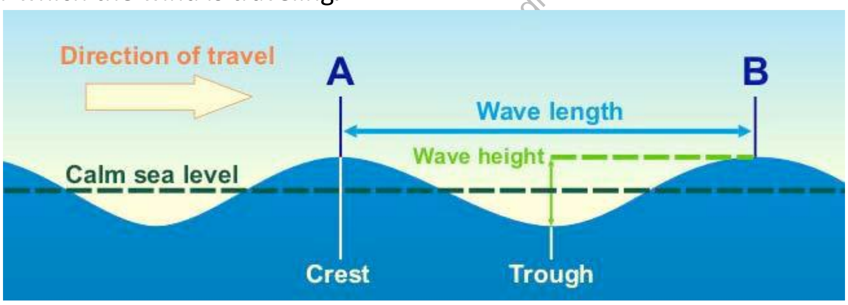
- Meanders
- Oxbow lakes
- Floodplains

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.

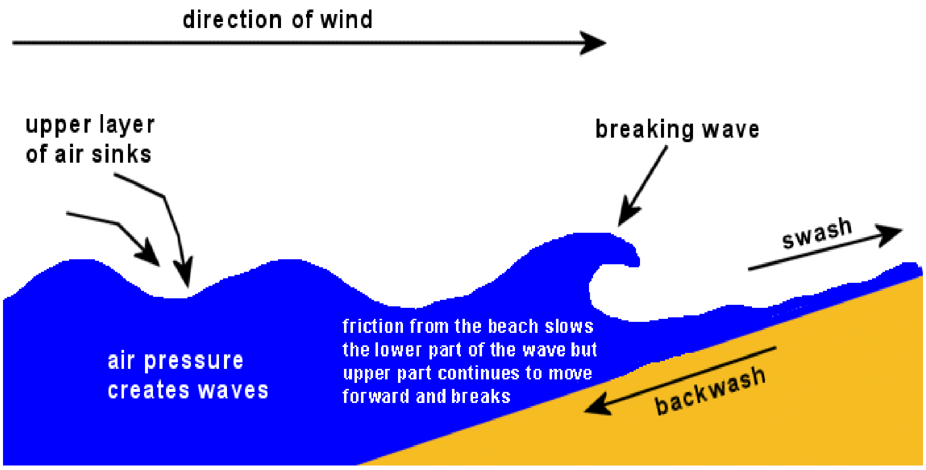
Tides and currents when come in contact with the shore have very little direct impact on the coastline. Instead, Waves are the prime agents of erosion in coastal regions. Waves are the result of transfer of energy from atmosphere to water by the wind moving over the water surface. The size of a wave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

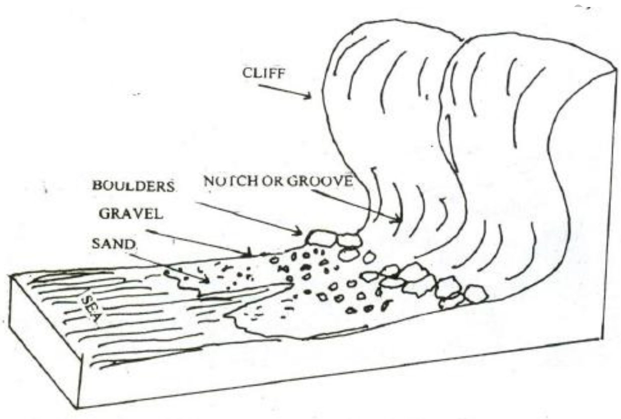


Figure No. 3- Cliff

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.

Student Notes:

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

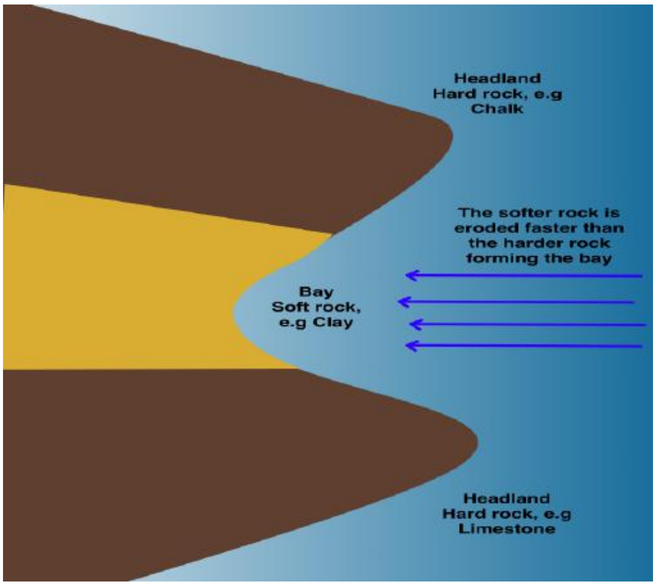


Figure No. 4- Formation of Headlands and Bays

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 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

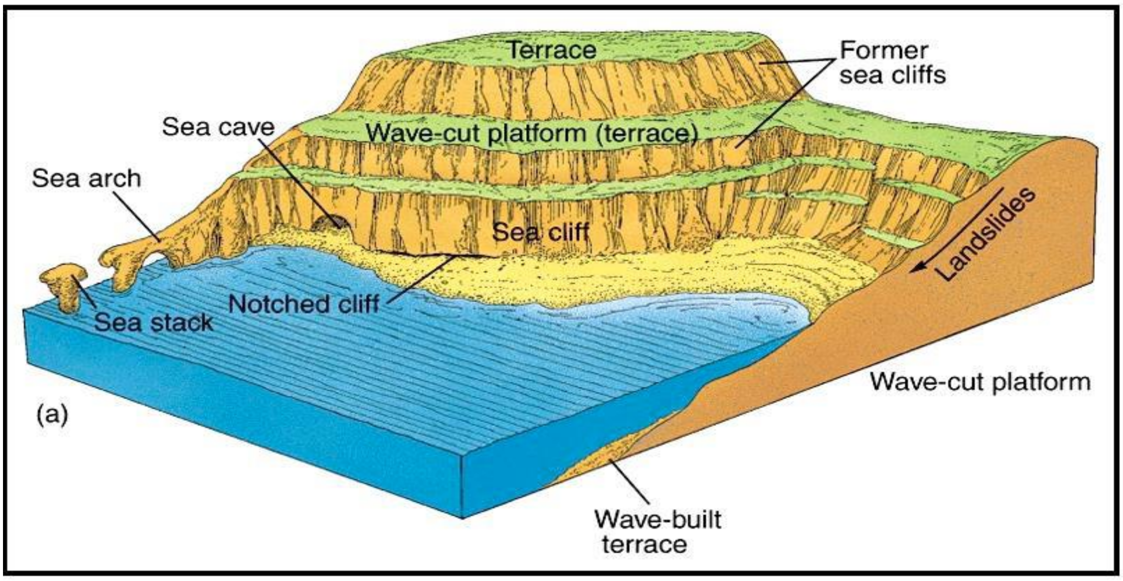


Figure No. 5-Coastal Erosional Features

Student Notes:

Student Notes:

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**

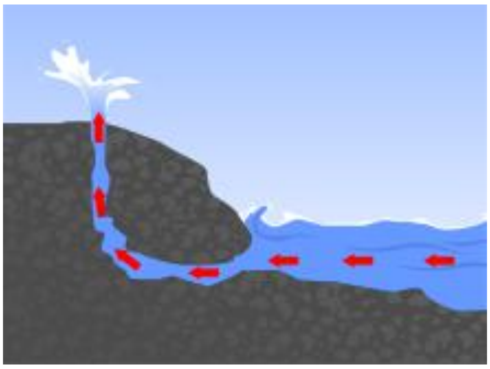


Figure No. 6- blow holes

8.4. Depositional Features

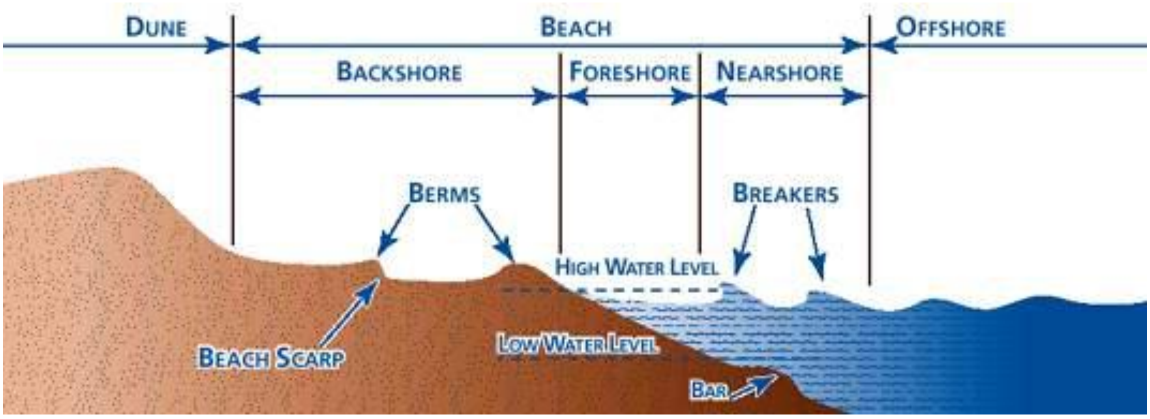
The sea waves also transport the eroded materials and deposit these at other places. Landforms resulting from deposition include platforms, beaches, bars & tombolos.

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.

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.



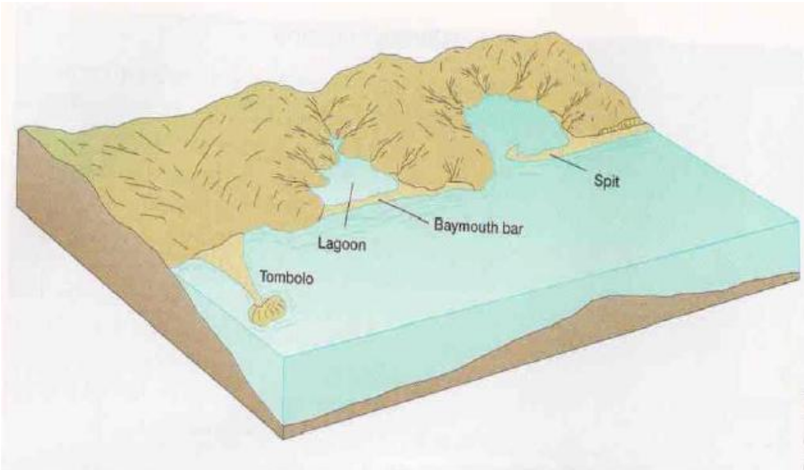
Beach and related features

8.4.3. Bars, Spits and Tombolo

Student Notes:

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.

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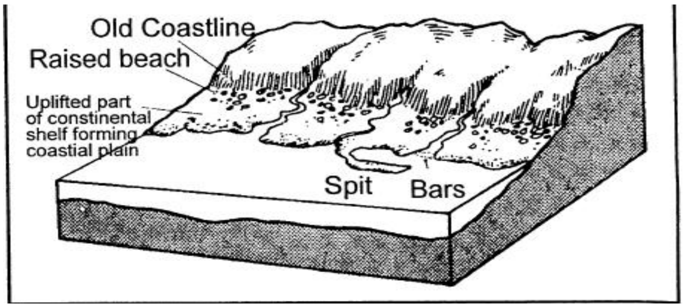
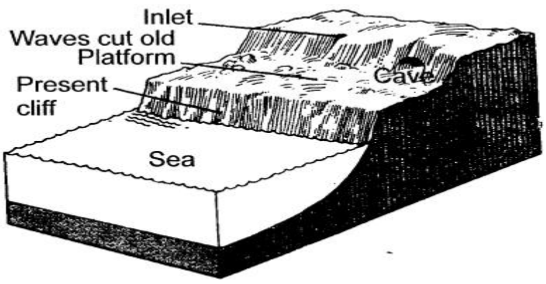


Emergent upland coast

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.



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

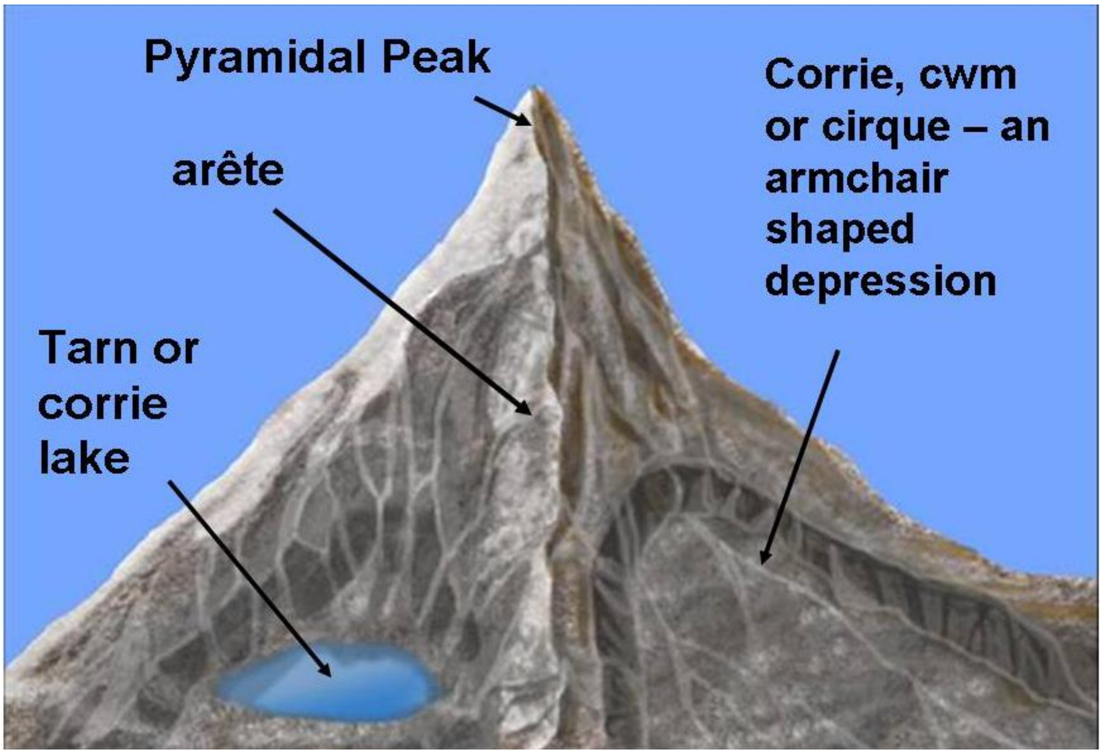
This is a narrow, knife edge ridge separating two corries

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.

Student Notes:

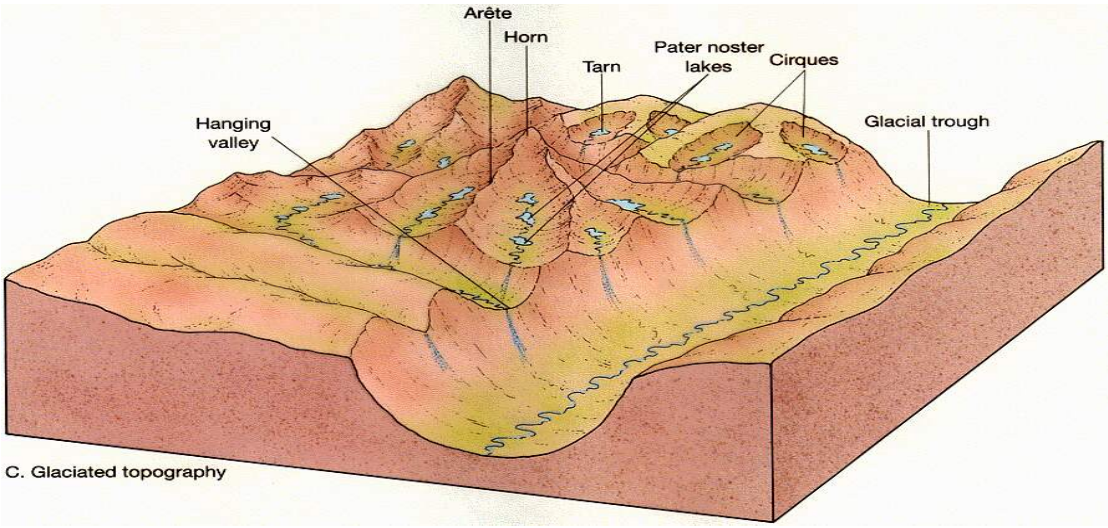
Figure no.2- Bergschrund

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.

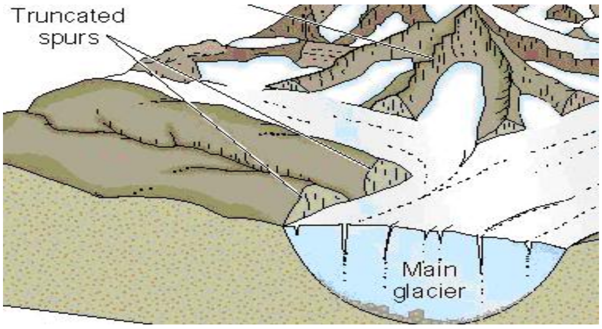


Glacial Erosional Landforms

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.**

Student Notes:

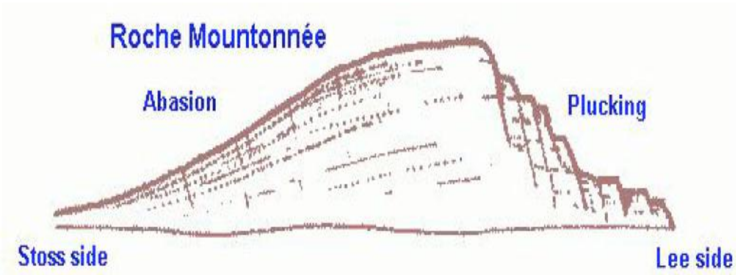


9.1.9. Paternoster lakes

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

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.

<u>The landforms created by glacial erosion are:</u>

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.

Student Notes:

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.

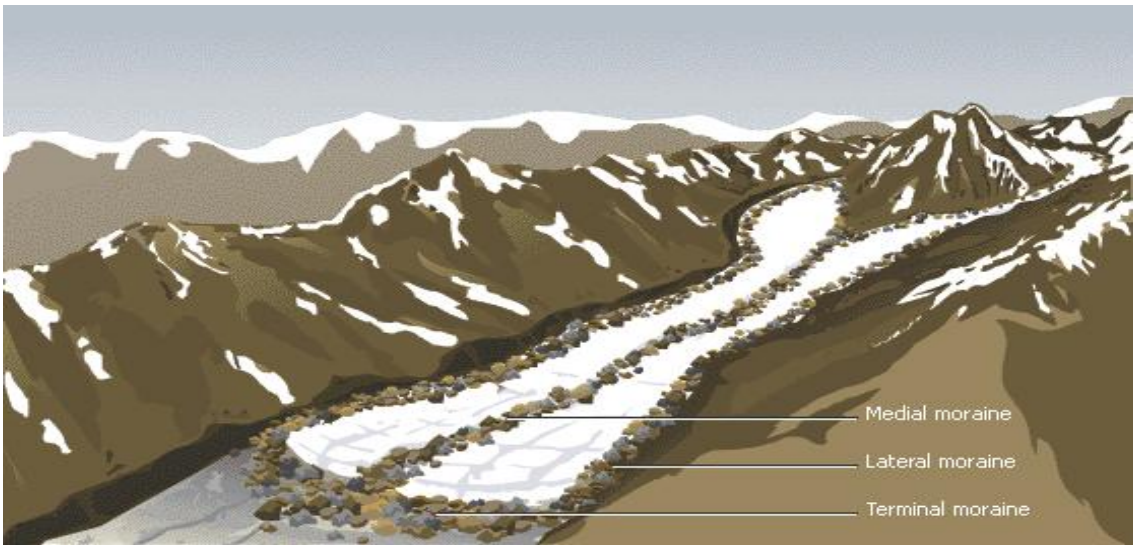
Different types of moraine

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**.

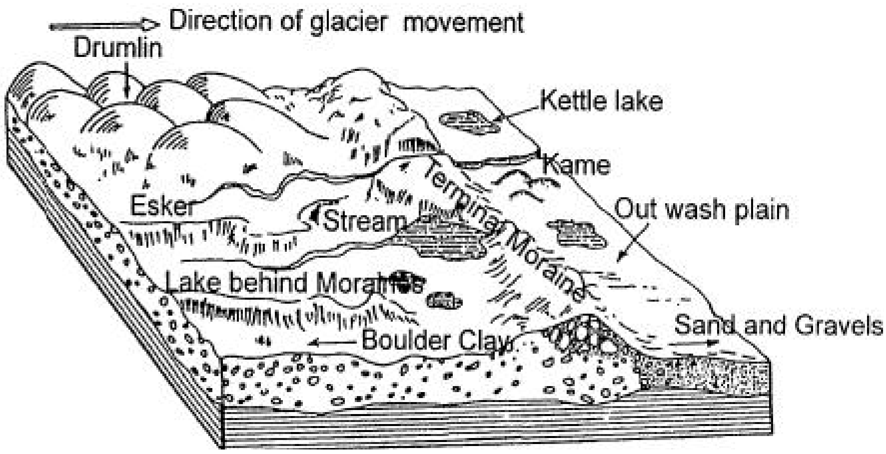
9.2.7. Eskers

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.

Student Notes:



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.
- ***Contintiality*** 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.

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.

- **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

Student Notes:

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.

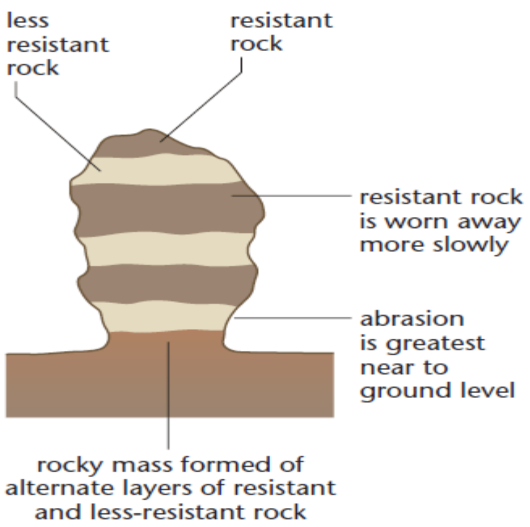
Abrasion or Corrosion: In the process of abrasion, winds pick up dust and sand and drive them with tremendous force against the rocks. In fact, in the desert and semi-desert areas, winds carry with them enormous quantities of sand, dust and small angular fragments which act as tools of erosion as they 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

10.2.4. Yardangs

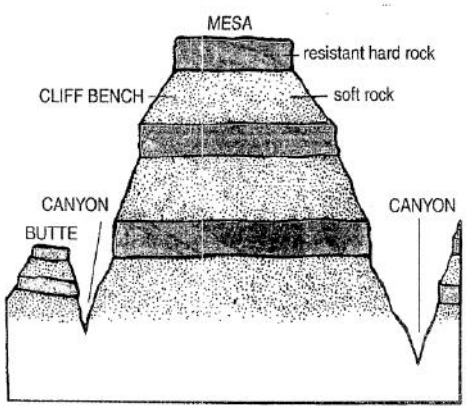
A yardang is a streamlined hill carved from bedrock or any consolidated or semi-consolidated material by the dual action of wind abrasion, dust and sand, and deflation.

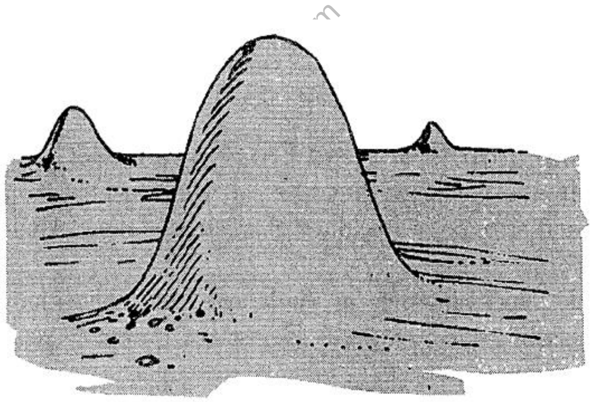
10.2.5. Zeugens

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.

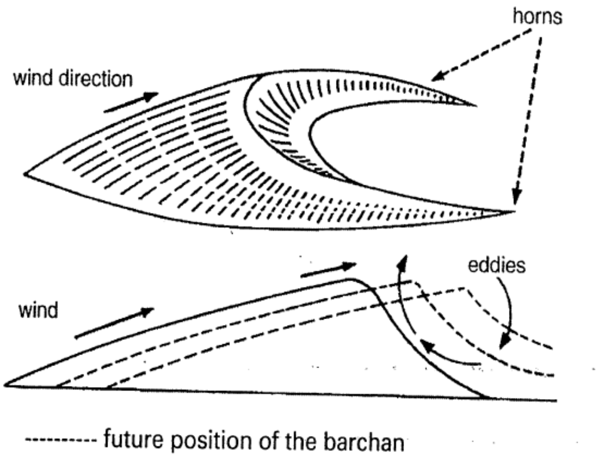
Ripple Marks: Ripple marks are small scale depositional features of sand. This pattern is produced in unconsolidated sediments by the agents of erosion-like wind. Ripples may be either longitudinal or transverse.

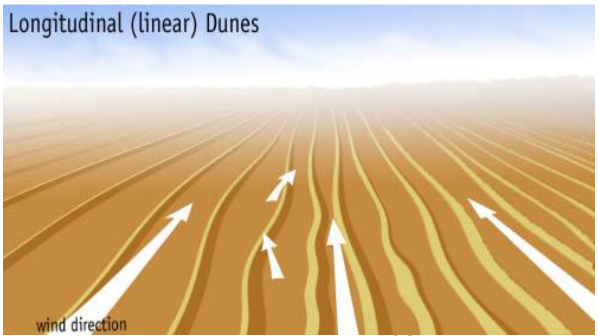
Student Notes:

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

Student Notes:

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

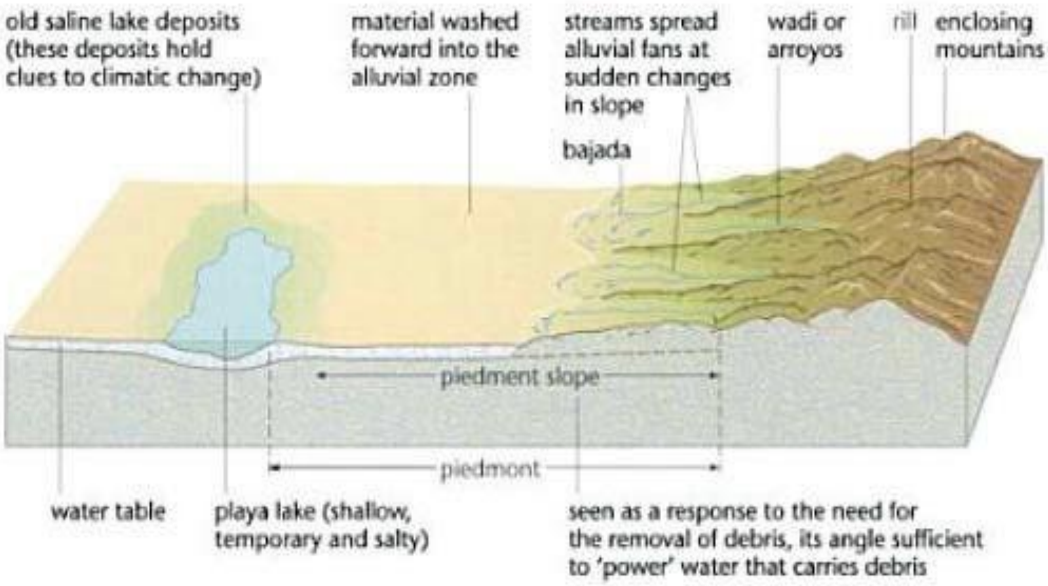
It is an erosional plain formed at the base of the surrounding mountains scraps.

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

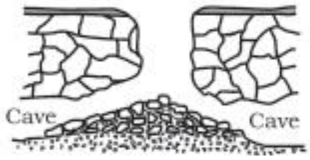
Student Notes:

11.1. Erosional landform

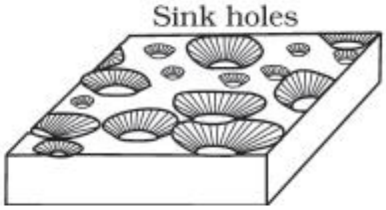
11.1.1. Sink Holes, Swallow Holes, Dolines and Uvalas/valley sink

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

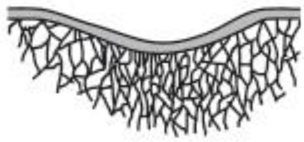
Section of Collapse sink



Sink holes



Swallow hole in section

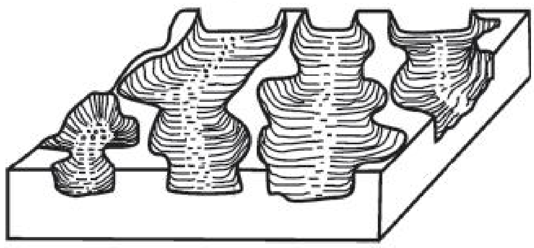


Gradual enlargement of sink holes due to continuous dissolution of limestones result in the coalescence of closely spaced sink holes into one large hole which is called **Swallow hole.**

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.

Valley sinks/Uvalas



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.

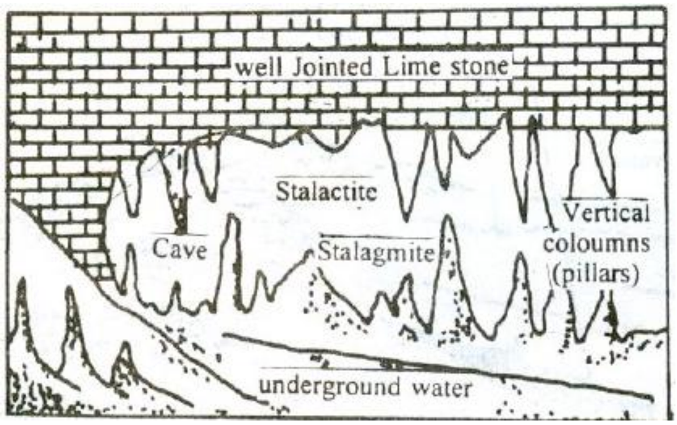
Student Notes:

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.

13. Previous Years UPSC Mains Questions

1. Major hot deserts in northern hemisphere are located between 20-30 deg N latitudes and on the western sides of the continents. Why? (2013)

14. Previous Years Vision IAS Test Series Questions

1. Describe the formation of flood plains. Also illustrate why people live in flood prone zones.

Approach:

Describe formation of flood plain and discuss significance of flood prone area for human settlement.

Answer:

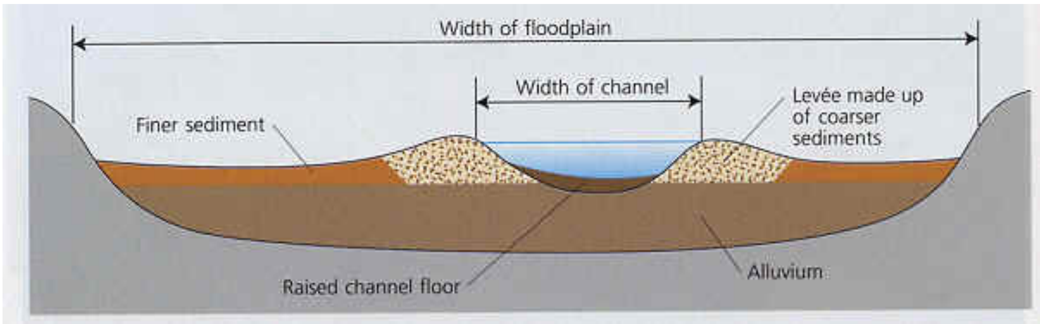
The Flood Plain is the area of alluvial deposits found beside the river in its lower course.

Student Notes:

Student Notes:

Flood plains are made by a meander eroding sideways as they travel downstream. When a river breaks its banks and floods, it leaves behind layers of alluvium (silt). These gradually build up to create the floor of the flood plain. Floodplains generally contain unconsolidated sediments, often extending below the bed of the stream. These are accumulations of sand, gravel, loam, silt, and clay. The heavier and coarser sediments are first deposited at the river's edge. The finer particles are being deposited a little further away from the river.

Floodplains can support particularly rich ecosystems, both in quantity and diversity. Wetting of the floodplain soil releases large amount of nutrients: those left over from the last flood, and those that result from the rapid decomposition of organic matter that has accumulated since then. This makes floodplains particularly valuable for agriculture. This makes these areas an attractive location for human settlement.



Therefore many towns have been built on floodplains, where they are highly susceptible to flooding, for a number of reasons:

- access to fresh water;
- the fertility of floodplain land for farming;
- cheap transportation, via rivers and railroads, which often followed rivers;
- ease of development of flat land

Foodplain areas today are home to some of the largest urban settlements, nine of the ten largest urban agglomerates in the world(United Nations, 2012) are located in deltas or floodplain areas, with most of them in the global South.

Thus Floodplains provide amenities, risks and rewards. It can be argued that over a long enough period of time, the occupant of the floodplain will lose, i.e., the risk will exceed whatever advantage derived from living on the floodplain. However, humans have always been attracted to floodplains because of their many sustaining attributes. But human development and industrialization take a toll on the natural functions of the floodplains. Development in the floodplains causes decreases in water quality, loss of wildlife habitats, and an increase in severity and frequency of flood losses. Understanding the importance of maintaining the natural functions of floodplains can lead to better floodplain management approaches that will better protect the natural and beneficial functions of floodplains.

2. Explain the differences between fold and block mountains, with examples.

Approach:

- Compare the process of formation of both the mountain types.
- Compare the characteristic features – size, elevation of both the mountain types.
- Provide examples.

Answer:

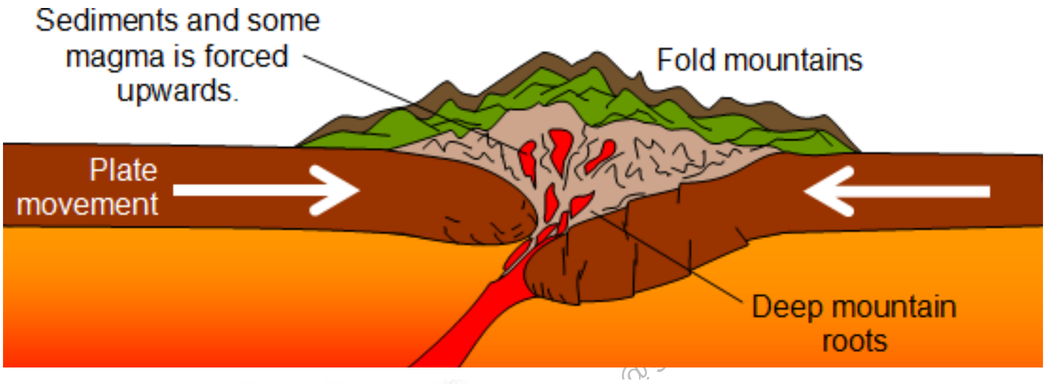
The Block and the Fold mountains, although are both uplifted physical features, yet from their formation to their later life, they are extremely different. These differences can be pointed out as under.

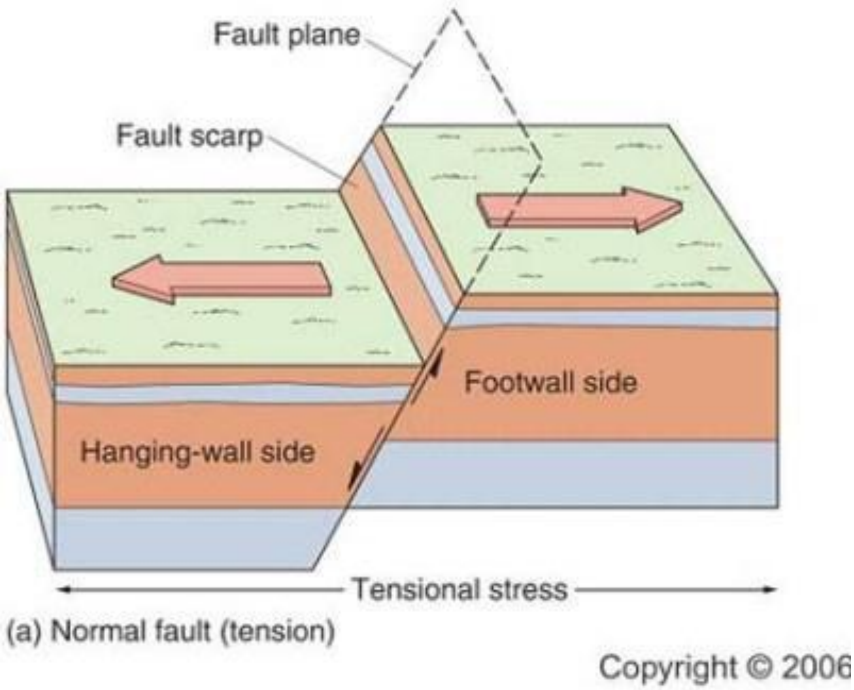
Formation of the mountains:

- **Fold Mountains**: They are produced when tectonic plates move towards each other. The resulting compressive force cause wrinkling or folding along the lines of weakness.
- **Block Mountains:** When the fault develops in the earth's crust by either compressive or tension experienced by it, it uplifts a certain portion of the land leading to formation of the Block Mountain.

Features:

- **Fold mountains**:
  - Very high but gradual elevation mountains.
  - They contain many active volcanoes e.g. around circum- pacific fold mountain system
  - Contain mineral rich resources
- **Block**
  - Comparatively elevation is much lower
  - Leads to formation of steep blocks enclosed by faults, rift valleys.





Student Notes:

Example:

- **Fold**: Most Widespread Mountains found throughout the world. Himalyas in the Central Asia, India and China are examples of it. Rockies in America, Andes in South America and Alps in Europe are examples of it.
- **Block Mountains:** Black forest of Rhineland, Hunsruck Mountains, East African Valley system, and the mountains surrounding the Narmada Rift Valley in India.

3. What are Endogenetic forces? Illustrate their role in the formation of various landforms.

Approach:

- Write about origin of endogenetic forces.
- Classify the forces based on (i)Direction of movement, (ii) Scale of operation and intensity.
- Describe the landforms associated with each categorisation of forces.

Answer:

The forces originating from within the earth are called as endogenetic forces. Their origin is related to the thermal conditions of the earth's interior. They cause both horizontal and vertical movements at both local and continental scale. Such movements are manifested in contraction and expansion of rocks because of varying thermal conditions and temperature changes inside the earth. This expansion/contraction generates the forces of push/pull which leads to formation of various landforms.

These movements motored by the endogenetic forces introduce various types of crustal irregularities which give birth to a number of relief features on the earth's surface (e.g. : mountains, plateaus, plains, lakes, faults, folds). Volcanic eruptions and seismic events are also the expressions of endogenetic forces.

On the basis of intensity, endogenetic forces can be divided into:

- Diastrophic forces
- Sudden forces

Diastrophic forces and movements:

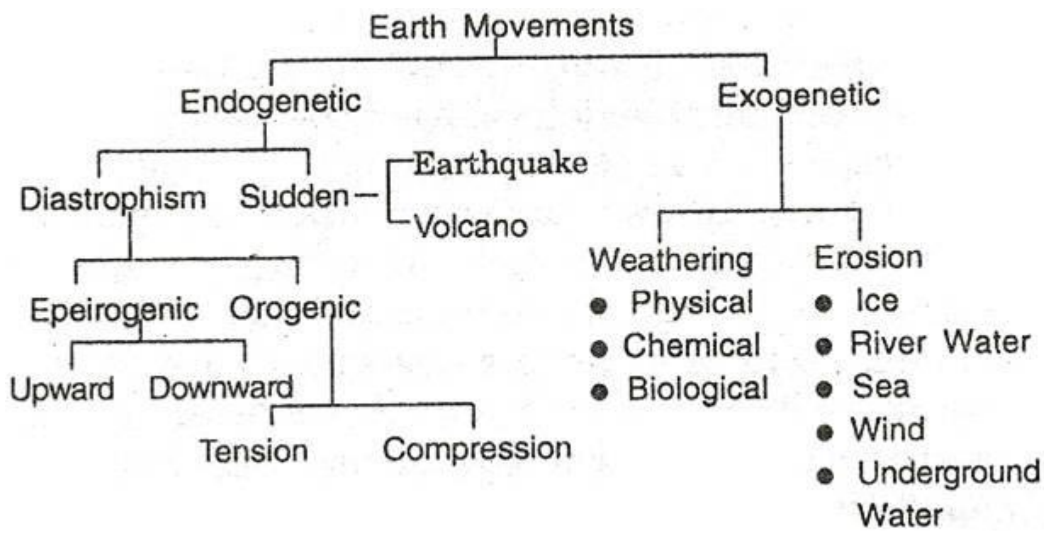
This includes both vertical and horizontal movements which are caused due to forces deep within the earth. These forces, also termed as constructive forces, affect larger areas of the globe and produce meso level reliefs. These diastrophic forces and movements are further divided into two groups:

- Epeirogenetic or continent building movements, which cause upwarping and downwarping.
- Orogenetic movements or mountain building movements, which cause tension and compression.

Sudden/Catastrophic forces and movements:

Sudden movements caused by endogenetic forces cause sudden and rapid events that lead to destruction at and below the earth's surface. Events like volcano and earthquake are called extreme events and become disastrous hazards. But these forces are also creative in nature e.g. volcanic eruptions result in the formation of volcanic cones and mountains while fissure flows of lavas form extensive lava plateaus (e.g. Deccan plateau of India , Columbia plateau of USA).

Student Notes:



Student Notes:

4. ***Continental shelves are the seaward extension of the continent from shoreline and have enormous economic and strategic significance. Elaborate.***

Approach:

- Briefly describe continental shelves and their formation.
- Major part of answer should focus upon economic and strategic significance of the continental shelves like resources, demarcation of EEZ etc.

Answer:

- The **Continental Shelf** is the gently sloping undersea plain between a continent and the deep ocean. It is the edge of a continent that lies under the ocean.
- A continental shelf extends from the coastline of a continent to a drop-off point called the shelf break. From the break, the shelf descends toward the deep ocean floor in what is called the continental slope.
- Even though they are underwater, continental shelves are part of the continent. The actual boundary of a continent is not its coastline, but the edge of the continental shelf.
- The widths of the continental shelves vary. Along parts of the U.S. state of California, for example, the continental shelf extends less than a kilometer. But along the northern coast of Siberia, the shelf extends about 1,290 kilometers. The average width of a continental shelf is 65 kilometers.

Economic Significance

- Shelf seas occupy about 7% of the area of the world's oceans but their economic importance is significantly greater
- Shallowness of continental shelves enables sunlight to penetrate through water which encourages growth of planktons. Therefore they are the worlds richest fising grounds, eg Grand banks, Dogger Bank and Sunda Shelf.
- Most of world's greatest ports are located on continental shelves like Honkong, Singapore, Rotterdam and Hamburg.
- They are rich in oil and gas deposits,hence they are important areas of oil and gas extraction. eg Persian Gulf, North sea and Bass strait.
- Deposits of minerals such as zircon, monazite, magnetite, mettalic nodules etc are found over the continental shelves.
- the seas on continental shelves provide the main source for livelihood and a focus for many coastal communities.

Strategic Significance

- Sovereign rights of the nations are defined by the 1982 United Nations Convention on the Law of the Sea.[15] which created the 200 nautical mile exclusive economic zone and extended continental shelf rights for states with physical continental shelves that extend beyond that distance. Thus help in demarcation of exclusive economic zone and maritime boundaries of nations. Hence they are significant from security perspective.
- From resources perspective, they contain several futuristic resources like gas hydrates, illeminite, poly metallic nodules etc. Thus they are strategically important.

Continental shelves are the region where humanity predominantly interacts with the sea. Therein lies their significance.

5. *Ocean basins are in a way similar to the landforms. Explain all the relief features shown by the basins with illustrations.*

Approach:

- Explain the similarity between oceanic relief and the continental landforms.
- Explain the relief features of oceanic basins.
- Give an illustration of these features.

Answer:

The ocean basin exhibits complex and varied features as those observed over the land. The continental and oceanic landforms are similar in some aspects.

For example, the submarine canyons are deep valleys as we seen on the land like the Grand Canyon of the Colorado river. The ocean basin/floor comprises of the world's largest mountain ranges, deepest trenches and the largest plains.

However, the oceanic relief features have some peculiar features of their own.

Major relief features

- **Continental shelf-**the shallowest part of the ocean with an average gradient of 1^{o} or even less.
- **Continental slope**-it connects continental shelf and the ocean basin. Canyons and trenches are observed here.
- **Deep sea plain-**it is the flattest and smoothest regions of the world comprising of fine grained sediments like clay and silt.
- **Oceanic deeps or trenches-**it is the deepest part of the ocean. It is associated with active volcanoes and earthquakes.

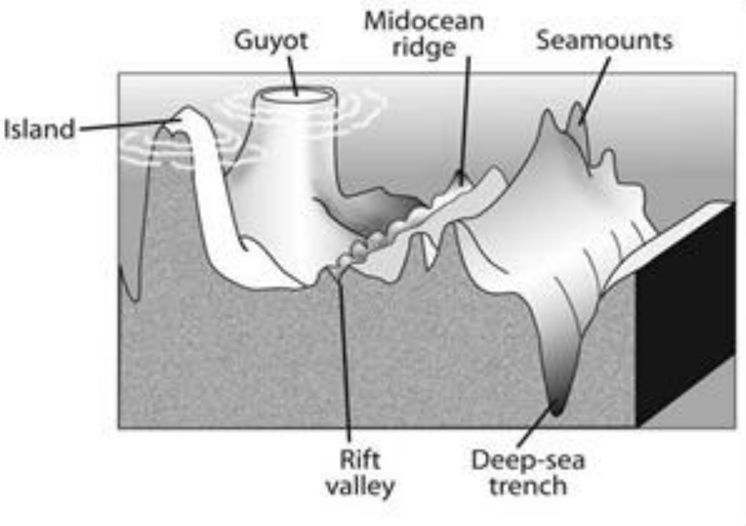
Minor relief features

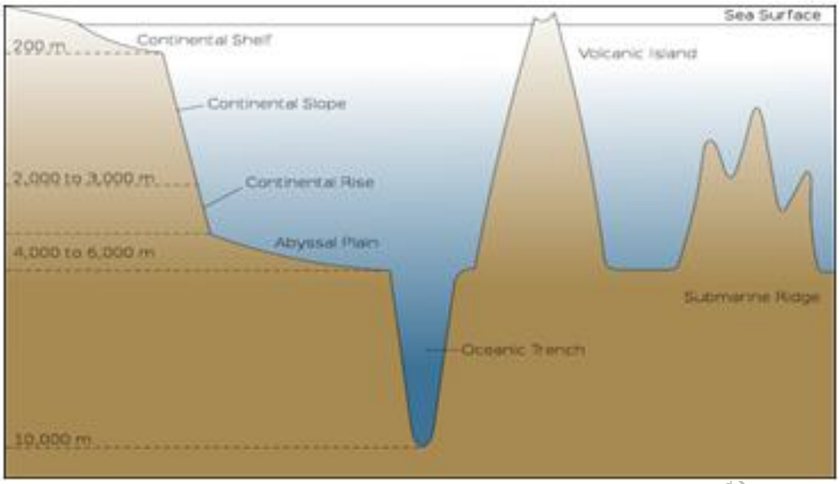
- **Mid oceanic ridges-**it comprises of two chains of mountains separated by a large depression. The peaks can be as high as 2500 m.
- **Seamount-**it is a mountain with pointed summits, which does not reach the surface. These are volcanic in origin.
- **Submarine canyons-**these are deep valleys sometimes found cutting across the continental selves and slopes**.**
- **Guyots-**it is a flat topped seamount. They show evidence of gradual subsidence through stages to become flat topped submerged mountains.
- **Atoll** these are low islands found in the tropical oceans consisting of coral reefs surrounding a central depression.

Student Notes:

Some of the above features are illustrated in the figure below:

Student Notes:



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INSPIRING INNOVATION
7 IN TOP 10 SELECTIONS IN CSE 2019
2 AIR
JATIN KISHORE
3 AIR
PRATIBHA VERMA
6 AIR
VISHAKHA YADAV
7 AIR
GANESH KUMAR BASKAR
8 AIR
ABHISHEK SARAF
9 AIR
RAVI JAIN
10 AIR
SANJITA MOHAPATRA
9 IN TOP 10 SELECTIONS IN CSE 2018
1 AIR
KANISHAK KATARIA
2 AIR
AKSHAT JAIN
3 AIR
JUNAID AHMAD
DELHI
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