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Indira Gandhi National
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BGGCT-131
PHYSICAL GEOGRAPHY

Block

1

GEO-TECTONICS

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PHYSICAL GEOGRAPHY: COURSE INTRODUCTION

Physical Geography is a core course in B.Sc. General programme with Geography offered as per UGC-CBCS at IGNOU. Physical Geography is one of the two major branches of systematic geography, the other one being human geography. It is the study of planet and its systems. It is concerned with all activities found in its four spheres, that is, lithosphere, atmosphere, hydrosphere and biosphere. In this course we study about all these spheres except biosphere which is covered in detail in the core course on environmental geography. Environmental geography is also a sub-branch of Physical Geography though it gives due importance to human component that is capable of transforming the environment. This course on Physical Geography is divided into 4 blocks.

Block 1 deals with the origin of Earth and solar systems. You will study about the favorable conditions prevailing on Earth which makes Earth a suitable planet for living organisms. You will also get acquainted with the interior of Earth. You will also know how the upstanding parts on Earth are maintaining equilibrium with low lying areas while studying the principle of isotsasy.

Block 2 introduces you to lithosphere and various processes operating herein. You will learn about different rocks types that exist on Earth. You will also learn about processes that have led to the drift of continents, formation of mountains and different plate mountains etc.
You will also read about endogenetic forces and exogenetic process, which is responsible for changing the face of Earth.

Block 3 gives a detailed description about atmosphere. You will study about composition and structure of atmosphere, basics of climatology and difference between weather and climate. You will learn about the importance of incoming solar radiation and how it heats up the Earth and how it is equal to outgoing terrestrial radiation. You will also study how pressure belts are formed and how difference in air pressure leads to the blowing of winds. Here you will also get acquainted with different types of winds, that is, planetary, seasonal, local etc. You will also study about atmospheric humidity and how it leads to precipitation. In the last unit of this block, you will also get acquainted with climatic classification of Koeppen.

Block 4 covers the entire hydrosphere. In the first unit of this block you will get a detailed description of hydrosphere which is the sum total of all water content an Earth whether it is the ocean water, or water in lakes, rivers, canals and other water bodies, weather it is frozen water in the form of glaciers and ice caps or water frozen in soil. It could also be atmospheric water in the form of water vapour. In the remaining four units of this block, you will study about oceans, as oceans have about 97.5% of the water on Earth. You will get acquainted with the bottom reliefs of oceans, temperature and salinity of oceans, oceanic tides and currents and lastly about ocean deposits.

So we will wish you good luck for studying this course

BLOCK 1: GEO-TECTONICS

In this block you will study about theories related to the origin of Earth. You will also learn about the conditions that make Earth a living planet, that is, a planet where life exists. You will also read about interior of Earth and evidences and views of renowned geoscientists that have helped to investigate the interior of Earth, its structure and composition. Finally you will also be acquainted with the principle of isostasy, due to which there is a state of equilibrium between the upstanding parts and low lying areas on Earth. This block is divided into 4 units.

In unit 1 you will learn about different views and theories regarding the origin of Earth like the gaseous, nebular, planetesimal, tidal and big bang theories. You will also study about solar system and about different planets in the solar system.

In unit 2 you will get a brief description of different spheres of Earth, that is, lithosphere, atmosphere, hydrosphere and biosphere. You will learn about ecosystems and how life is able to flourish on Earth.

Unit 3 explains to you the interior or Earth. Here you will study different views that were given by geoscientists that helped to know about the interior of Earth which is the most unexplored part of Earth.

Unit 4 acquaints you with the principle of isostasy due to which there exists a balance between the upstanding parts and the low lying areas. You will also study about the views of Airy, Pratt, Hayford, Bowie, Joly, Holmes regarding this.

So after studying this block, you should be able to:

- describe Earth and the solar system;
- discuss the processes that led to the origin of Earth and solar system and also summarise various concepts related to it;
- elaborate on different views given to construct about the interior of Earth;
- explain the principle of isostasy and also summarise different views regarding it .

So we wish you good luck for studying this block

UNIT 1

ORIGIN OF EARTH

Structure

1.1 INTRODUCTION

You might have studied the basics related to origin of the Earth in your school. And you have fairly good idea about it. In the very beginning unit of this course we will further familiarize you with this theme in more detail. The academic inquisitiveness may make you think about many questions related with the origin of Earth. For example, how we can define the Universe? What are its basic concepts and so on? In simpler ways Universe has been defined as the totality of existence. It means that the entire gamut of astronomical bodies comprising planets, stars, galaxies, the contents of intergalactic space, the smallest subatomic particles, and all particles of matter and energy are included in the Universe. Human have always been eager to know more and more about it. You will study the basic concepts of the Universe in the Section. 1.2.

Various astronomical objects like stars, planets, etc. orbit the Sun in a constant manner which we collectively know as **Solar System**. It consists of nine planets, some dwarf planet, 63 moons, millions of smaller astronomical bodies like asteroids and comets, and it also includes huge quantities of gas and dust particles. The planets along with their satellites revolve round the Sun. It is the most important part of the Universe and suitable environ for higher forms of life are found only in one of the inhabitable planet which is known as Earth. You will understand all about this Solar System from Section. 1.3. You will also study the hypotheses related to the origin of Earth and the solar system from the Section. 1.4.

Expected Learning Outcomes

After studying this unit, you should be able to:

- explain the basic concepts of Universe;
- define the Solar System;
- explain various hypotheses related to the origin of Earth and the solar system.

1.2 BASIC CONCEPTS

1.2.1 Earth as a Blackbody

Can you visualize that the Earth is much close to being a black body radiator? It means that a black body can absorb heat at any wavelength. But it also emits heat at a particular wave pattern. It is on account of the Earth's closeness to being a black body radiator which is responsible for the greenhouse effect as it can absorb solar energy at any wavelength (mostly short wavelength i.e. incoming terrestrial radiation), but emits it in a narrow band of radiation. Do you know how the evolution of various life forms became possible on the Earth? It is this green house effect which makes life possible on Earth otherwise the Sun's radiation would also be radiated away. Though the Earth is close to being a black body radiator but the energy absorbed by it is at different level (e.g. ultraviolet rays being absorbed by ozone layer). The Earth reflects about one third of the energy reaching it, so it appears to be quite bright, but it is close to being a black body radiator.

1.2.2 Rotation and Revolution of Earth Planets and Satellites

You all are familiar that Earth's rotation is the rotation of the solid Earth around its own axis. The Earth rotates from West to East. As viewed from the North Star or Pole Star the Earth turns anti clockwise. The Earth's axis of rotation meets its surface at the North Pole, in the northern hemisphere. The South Pole is the other point where the axis of rotation intersects its surface, in Antarctica. The Earth rotates once in every twenty four hours with respect to the Sun and once every 23 hours 56 minutes and 4 seconds with respect to the stars. Earth's rotation is slightly slowing with time, thus the day was shorter in the past, this is due to the tidal effect of the moon has on the Earth's rotation. Atomic clock show that a modern day is longer by about 1.7 milli seconds then a century ago, slowly increasing the rate at which UTC is adjusted by leap seconds. You know that the rotation of the Earth is responsible for the alternate periods of light and darkness that gives us day and night.

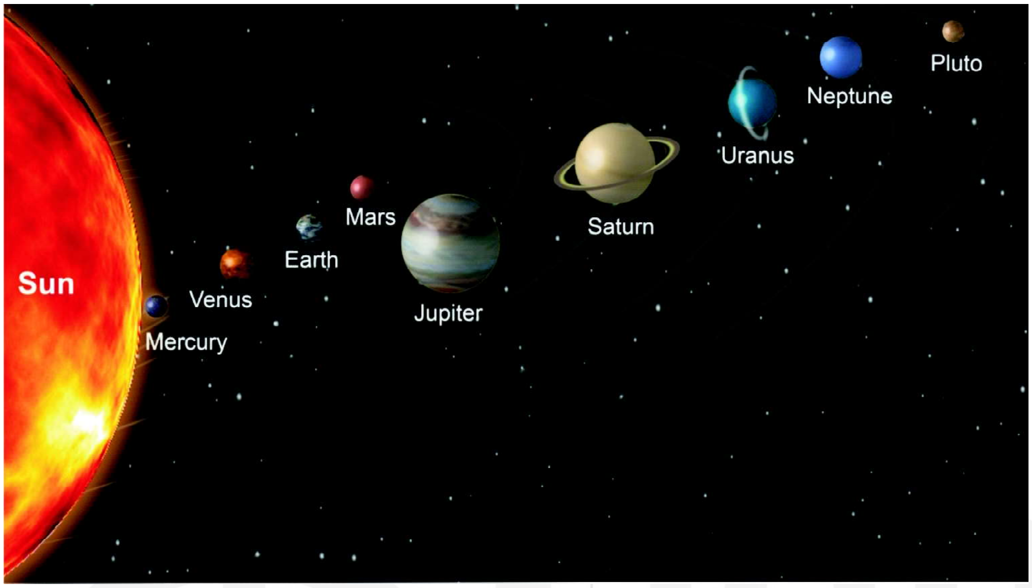

Fig. 1.1: Major Planets in the Solar System.

While the Earth's revolution is the complete orbit of the sun by the Earth. This is called a year and takes 365.25 days to complete one orbit. The path of this revolution, the Earth's orbit is an ellipse rather than a circle. The Earth is consequently nearer to the Sun in January than it is in July; the difference between its maximum and minimum distances from the Sun is 3 million miles (4.8 million kilometers). This difference is not great enough to affect climate on the Earth. If you were to look down on the Solar System from "above", that is, so that the Sun is seen to rotate anti-clockwise, you would see Earth revolve around the Sun in anti-clockwise direction. It is also the direction in which both the Sun and the Earth rotates.

Diagrammetric representation of major planets alignment in the solar system is presented in Fig. 1.1. In fact, the planets rotate and most of the moons revolve around the planets in anti-clockwise direction. This common anti-clockwise direction of rotation/revolution very likely reflects the rotation of the original cloud from which all components of the Solar System were formed. The **period of revolution** of the Earth around its orbit defines the year, one of the planet's natural time scales. The mean Sun-Earth distance is 149.5 million kms. This defines the Astronomical Unit. Two key positions along the orbit are **Perihelion**-the point of closest approach to the Sun. This occurs on ~3 January, when the Sun-Earth distance is ~146 million kilometers. **Aphelion**-the point at which Earth is farthest from the Sun. This occurs on ~4 July, when Sun-Earth distance is ~156 million kilometers. The difference in distance between perihelion and aphelion (some 10 million kms) is small but important. One consequence is that Northern Hemisphere winters/Southern Hemisphere summers tend to be milder than Southern Hemisphere winters/Northern Hemisphere summers. In part, this helps to explain the existence of the very large ice cap in the Southern Hemisphere polar region. The dates of perihelion and aphelion change slowly with time because the whole orbit rotates slowly anti-clockwise in the ecliptic plane, and the shape of the orbit, as expressed by the eccentricity, changes over time. Always keep in mind that the revolution of the Earth in its orbit around the Sun is independent of the rotation around its axis. You can visualize the cycle of day and night on Earth from Fig. 1.2.

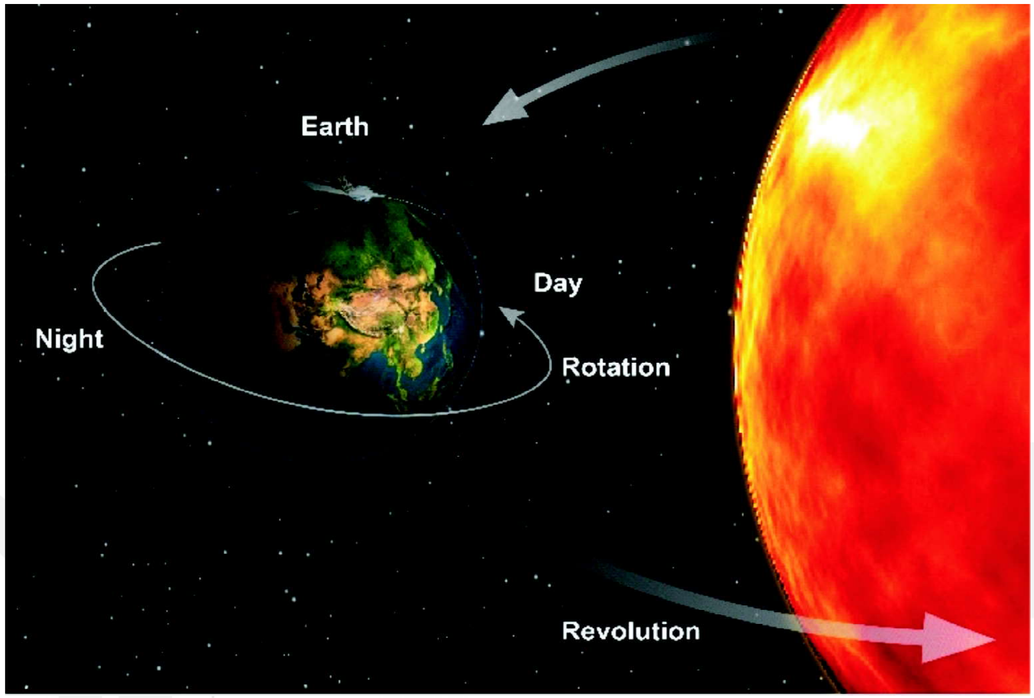

Fig. 1.2: Artistic impression of Earth's Rotation.

How will you understand the change in seasons? The change in seasons is caused by the tilt of the Earth's axis to the plane of its orbit, making an angle of 66.5°. When the northern end of the Earth's axis is tilted toward the Sun, the most direct rays of sunlight fall in the Northern Hemisphere. This causes its summer season. At the same time, the Southern Hemisphere experiences winters since it is then receiving indirect rays. Halfway between, in spring and in autumn, there is a time (see equinox) when all parts of the Earth have equal day and night. When the northern end of the Earth's axis is tilted away from the Sun, the least direct sunlight falls on the Northern Hemisphere. This causes its winter season.

1.2.3 Universe and Galaxies

Galaxies are sprawling space systems composed of dust and countless stars. The number of galaxies cannot be counted – the observable universe may alone contain hundred billion galaxies. Some of these are similar to our milkiway whereas others are quite different. The diameter of our galaxy milkiway is about 100,000 light years. It contains more than thousand million stars. Our Sun with its solar system is about 30 thousand light years away from the center of the milkiway. Like other stars, the Sun with its solar system is revolving around the center of the milkiway. The period of revolution is about 224×10^6 years. Sun has thus made only two complete rounds around the center of the milki way till now. The solar system revolves around the milkiway with the speed of 285 kilometers per second. Now we will discuss about various types of galaxies.

Classifications of Galaxies

It was astronomer Edwin Hubble who classified galaxies into four major types. These are known as Spiral, Barred Spiral, Elliptical and Irregular galaxies. Most of the nearby bright galaxies are spirals, barred spirals or elliptical. Let us learn more about the same.

- **Spiral Galaxies** have a bulge at the center and a flattened disk containing spiral arms. Spiral galaxies have a variety of shapes and are classified according to the size of the bulge and the tightness and appearance of the arms. The spiral arms, which wrap around the bulge, contain numerous young blue stars and lots of gas and dust. Stars in the bulge tend to be older and redder. Yellow stars like our Sun are found throughout the disk of a spiral galaxy. The disks of spiral galaxies rotate somewhat like a hurricane or a whirlpool.
- **Barred Spiral Galaxies** are spiral galaxies that have a bar-shaped collection of stars running across the center of the galaxy.
- **Elliptical Galaxies** do not have a disk or arms. Instead, they are characterized by a smooth, oval-shaped appearance. Elliptical contains old stars and possess little gas or dust. They are classified by the shape of the ball, which can range from round to oval (baseball-shaped to football-shaped). In contrast to the disks of spirals, the stars in elliptical galaxies do not revolve all around the center in an organized way. The stars move on randomly oriented orbits within the galaxy, like a swarm of bees.
- **Irregular Galaxies** are galaxies that are neither spiral nor elliptical. They tend to be smaller objects that are without definite shape, and tend to have very hot newer stars mixed in with lots of gases and dust particles.

In this section, you have learnt about four types of galaxies along with their characteristic features.

SAQ 1

a) What do you understand by Earth's revolution?

b) What causes change in season? When do we have summer season in Northern Hemisphere?

Spend 5 mins

1.3 THE SOLAR SYSTEM

The Solar System is believed to be formed nearly 4.6 billion years ago from the gravitational collapse of a giant molecular cloud. It consists of the Sun and the objects that orbit it, whether they orbit it directly or by orbiting other objects which orbits it directly. Of those objects that orbit the Sun directly, the largest nine are the planets that form the planetary system around it, while the remainder is significantly smaller objects, such as dwarf planets and Small Solar System Bodies (SSSB's) such as comets, and asteroids, etc. All planets differ in size. The planets located in the middle of the solar system are bigger in size than those on the sides. Geophysicists called this arrangement of planets as '*cigar shaped*'. The planets of the solar system can be classified into two groups: Inner or terrestrial planets and outer planets (Fig. 1.3).

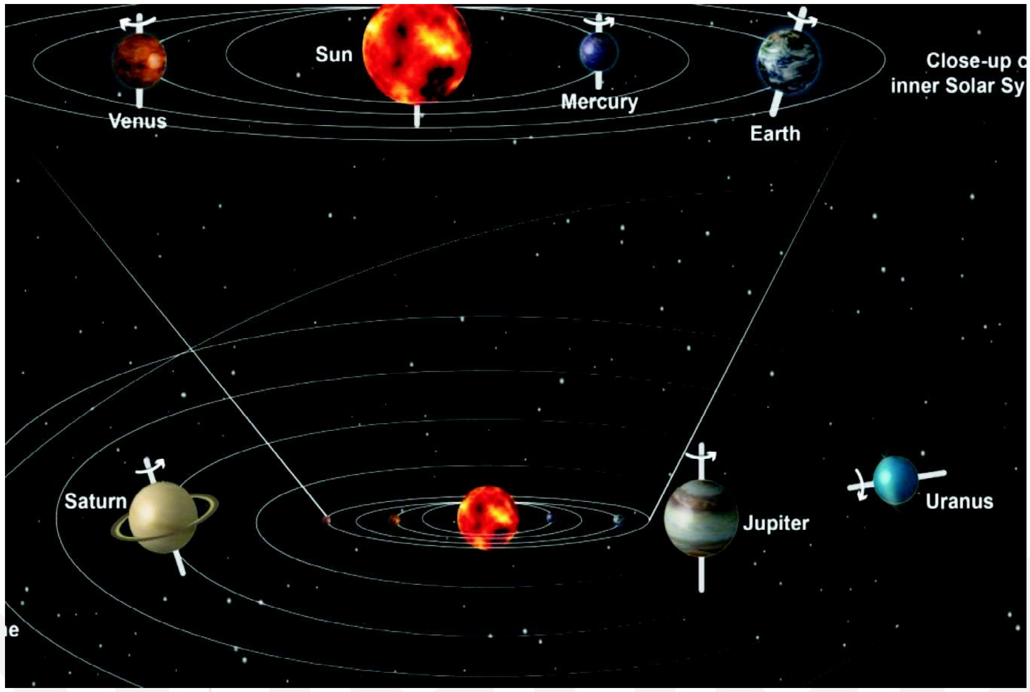

Fig. 1.3 : Artist's impression of the Solar System showing the inner Planets (Mercury to Mars) and the outer Planets (Jupiter to Neptune) and beyond (Credit: NASA).

Inner or terrestrial planets: The inner circle consists of four planets including Mercury, Venus, Earth along with Mars and Asteroids. These planets are called inner planets as they lie between the Sun and the belt of asteroids and are closer to Sun. They are called terrestrial which means Earth like, as they are made up of rocks and metals. These planets are comparatively small in size and have relatively higher density. Their speed of rotation is less. They either have no satellite or very less satellites for example the Earth has only one and Mars have two satellites.

The outer planets: They are also known as the giant planets or Jovian planets (Jupiter like) – the outer circle consists of five planets namely Jupiter, Saturn, Uranus, Neptune and Pluto. These planets are bigger in size and are less dense. They have thick atmosphere mostly composed of helium and hydrogen. Their speed of rotation and number of satellites are more compared to the inner planets.

The four smaller inner planets, Venus, Earth, Mars and Mercury also called the terrestrial planets, are primarily composed of rock and metal. The four outer planets, called the gas giants, are substantially more massive than the terrestrials. The two largest namely, Jupiter and Saturn, are composed mainly of hydrogen and helium. The two outermost planets, Uranus and Neptune, are composed largely of substances with relatively high melting points (compared with hydrogen and helium), called ices, such as water, ammonia and methane, and are often referred to separately as "ice giants". All planets have almost circular orbits that lie within a nearly flat disc called the ecliptic plane. The vast majority of the system's mass is in the Sun, with most of the remaining mass contained in Jupiter.

The Solar System also contains regions populated by smaller objects. The asteroid belt, which lies between Mars and Jupiter, mostly contains objects composed, like the terrestrial planets, of rock and metal. Beyond Neptune's orbit lie the ***Kuiper belt*** and scattered disc, linked populations of trans-Neptunian objects composed mostly of ices. Within these populations are several dozen to more than ten thousand objects that may be large enough to have been rounded by their own gravity. Such objects are referred to as dwarf planets. Identified dwarf planets include the asteroid ***Ceresand*** the trans-Neptunian objects Pluto and Eris. In addition to these two regions, various other small-body populations, including comets, centaurs and Inter-planetary dust, freely travel between regions. Six of the planets, at least three of the dwarf planets, and many of the smaller bodies are orbited by natural satellites, usually termed "moons" after Earth's satellite Moon. Each of the outer planets is encircled by planetary rings of dust and other small objects. The solar wind, a flow of plasma from the Sun, creates a bubble in the interstellar medium known as the ***heliosphere***. It extends out to the edge of the scattered disc. The ***Oort*** cloud, which is believed to be the source for long-period comets, may also exist at a distance roughly a thousand times further than the ***heliosphere***. The ***heliopause*** is the point at which pressure from the solar wind is equal to the opposing pressure of interstellar wind. The Solar System is located within one of the outer arms of the Milky Way, which contains about 200 billion stars.

Before giving a vivid description about hypotheses related to the origin of Earth and Solar System, it is of utmost importance to know some of the characteristics of the Solar System which are as follows:

- The axis of all these planets is tilted towards their orbital plains but it is tilted differently by different planets.
- All the planets rotate around their axis and the speed of rotation of these planets vary from each other.
- All these planets revolve around the Sun in anti-clockwise direction.
- The path of these planets is either circular or elliptical.
- All these planets are very small in size and mass when compared to the Sun.
- The Sun comprises about 98% of the Solar System.
- The distribution of angular momentum in the Solar System is of special type. According to the law of conservation of angular momentum the total angular momentum, of an isolated system remains constant. It means that if any body is rotating, the total amount of its angular momentum will always remain constant unless an external force is applied on the rotating body. Angular momentum is the product of the mass, angular velocity and the square of the radius of the rotating body. The distribution of the angular momentum in the Solar System is not same.

It is very interesting to know when we compare the angular momentum of the Sun with the angular momentum of other planets, we can observe that the Sun contains only 1.7% of the total angular momentum (Table 1.3.1). The remaining 98.3% of it constitutes the other planets of the Solar System. Contrary to it, the Sun possesses 99.9 % of the total mass of the Solar System whereas the planets contain only 0.1% of mass.

Table 1.3.1: Angular Momentum

Members of Solar System	Angular Momemtum
Mercury	0.03
Venus	0.69
Earth	1.00
Mars	0.13
Jupiter	725.00
Saturn	294.00
Uranus	64.00
Neptune	95.00
Pluto	1.00
Sun	20.00
Sum of the Solar System	1200.85

1.3.3 Asteroids and Planeteroids

Asteroids are minor planets, especially those of the inner Solar System. The larger ones are called planetoids. These terms have specifically been applied to any astronomical object orbiting the Sun that did not show the disc of a planet. There are millions of asteroids, many thought to be the shattered remnant of planetesimal bodies within the young Sun's nebula, which never grew large enough to become planets. The large majority of known asteroids lie in the belt between the orbits of the Mars and Jupiter. However, the other orbital families exist with significant population including the near Earth asteroids. Individual asteroids are classified by their characteristic spectra into three groups namely C type (carbon group) S type (stony) and M type (metallic). Only one asteroid *4 Vesta* which has a relatively reflective surface is normally visible to the naked eye only but in very dark skies and when it is in favorable position.

1.4 ORIGIN OF EARTH AND SOLAR SYSTEM

From time to time various scientists have given their concepts, hypothesis and theories in order to explain the origin and evolution of the Solar System. Such views and concepts may be divided into two groups: religious concepts and scientific concepts.

Religious concepts are discarded as they do not have logical and scientific base. The scientific concepts are generally based on hard sciences divided into two schools namely hot origin concepts and cold origin concepts.

According to hot origin concept, the planets are believed to have been formed from the matter which was either hot or was heated during the process of origin of the planets. On the other hand, the school of the cold origin concept explains the Solar System originated from the matter which was either initially cold or always remained cold. On the basis of the number of heavenly bodies involved in the origin of the Solar System and the Earth, the scientific concepts are divided into three groups: Monistic concept – one star hypothesis, dualistic concept (binary hypothesis) i.e. involving two Heavenly bodies, and Modern concept.

1.4.1 Monistic Concept

Monistic concept (one star hypothesis) – According to this hypothesis, the Solar System originated from one star due to the gradual evolutionary process. The hypothesis of Kant, Laplace, Roche and Lockear comes under this category.

1.4.1.1 Gaseous Hypothesis of Kant

The German philosopher, Kant, put forward his hypothesis in 1755 claiming that his hypothesis was based on sound principles of Newton's first law of gravitation and rotatory motion. According to him, innumerable particles of primordial matter were scattered in the universe. And, these particles started colliding against each other due to gravitational attraction. As a result of this collision, heat was generated. This changed the primordial matter from solid to liquid and from liquid to gaseous state. Thus the original cold and motionless cloud of matter became in due course a vast hot nebula and started rotating around its axis and with continuous rise in the number of primordial particles, the nebula expanded in size. Due to the continuous increase in size of nebula the speed of rotation became so fast that the centrifugal force exceeded the centripetal force. This created a bulge in the center of the gaseous mass. When this bulge increased in size, the rings started forming one by one and were separated from the middle part of the nebula and were thrown off due to centrifugal force. The residual central mass became the Sun and rest of the rings became the planets. By the repetition of the same process, the rings were separated from the newly formed planets. And the material of each ring condensed to form satellites of the concerned planets.

Critical analysis

1. Kant has not explained the source of the primordial matter.
2. Kant said that the particles of the primordial matter started colliding due to gravitation energy. He has not explained how the source of energy which caused motion of these particles (which were cold and motionless in initial state) suddenly became active.
3. According to science of law of motion, the collision of the particles can never generate rotatory motion.
4. Kant's assumption that the speed of rotation of the nebula increased with the increase in the size of the gaseous matter is also against the law of science of law of motion.

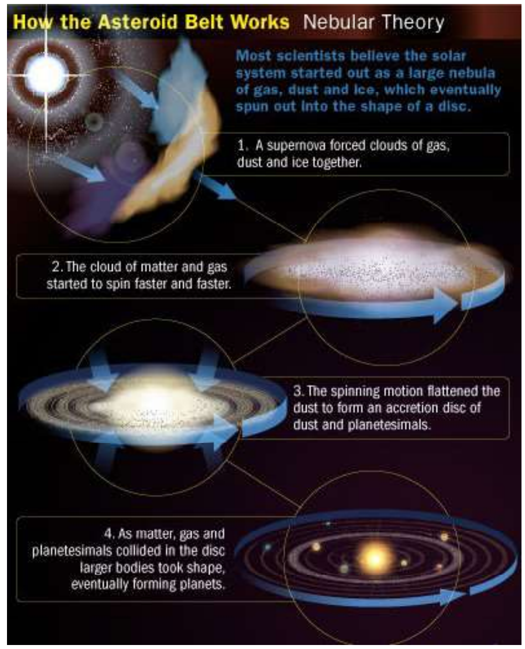

Fig.1.4 : The Nebular hypothesis describes how the Solar System formed from a cloud of gas and dust into a disk with the Sun at the center. This painting was made by an artist; it's not an actual photograph of a proto-planetary disk.

Conclusion

Though in the beginning, Kant's hypothesis received appreciation on a large scale. But, later it was disapproved as it was based on assumption and wrong application of Newton's law of gravitation and invalid concepts. But, then too, we cannot overlook the fact that it was the first scientific attempt ever made to solve the mystery of the origin of the Earth.

1.4.1.2 Nebular Hypothesis of Laplace

Kant had postulated his hypothesis before Laplace therefore got the advantage of refining this Hypothesis by removing the inherent weak points and inaccurate concepts of Kant's hypothesis. Thus, we may consider the Hypothesis of Laplace as the modified version of Kant's hypothesis. Para Laplace explained his concepts about the origin of Solar System and the Earth in his book entitled **"Exposition of the World Systems"** in the year 1796.

According to him, a huge and hot gaseous matter called nebula existed in the space which was continuously rotating on its axis (Fig. 1.4). This nebula was losing heat from its outer surface due to the process of radiation and was thus cooling and reducing in size and volume due to contraction on cooling. As the size and volume of the nebula decreased, the velocity of rotatory motion began to increase. It increased so much that the centrifugal force became greater than the centripetal force. A state came when the centrifugal and the gravitational pull became equal at the equatorial bulge which made it weightless. As a result, the rings started detaching i.e. separating from the equatorial bulge of the contracting nebula. The outer rings (layers) thus started separating from the nebula one by one. Each ring condensed at a point in the form of gaseous accumulation and started rotating around the nebula. This gaseous mass later cooled and formed as the planets. The remaining part of nebula thus became the Sun and the nine rings became the planets. The satellites were also formed by repetition of the aforesaid process. From this we can conclude that Laplace considered that the Solar System as well as the planets are all originated from the same source.

This hypothesis is of great importance. The rings revolving around Saturn is an excellent example that supports the Laplace's hypothesis. Besides this, there are many nebulas existing in the Universe which supports his view. When the diameter of the revolving mass reduces, its speed of rotation increases. This view of Laplace is in accordance with the laws of motion science. The presence of the same kind of elements in the formation of planets also proves his views right. According to Laplace, all planets have been formed due to cooling of the gaseous mass. The upper layer of this gaseous mass became solid but the inner part is still in liquid state. The liquid lava erupting from the volcanoes supports his hypothesis. It is for this reason that this hypothesis commanded respect for more than fifty years. But as there are two sides of a coin, this hypothesis also has its demerits.

Critical analysis

1. Laplace assumed that there existed a hot rotating nebula in the space. But he did not explain the source of origin of nebula and the source from where it received heat and rotation.
2. Laplace did not explain why only nine rings came out from the irregular ring detached from the nebula and why not more or less rings.
3. If the planets have been formed from the rotating nebula then the part of the nebula i.e. Sun should rotate at the highest speed due to decrease in size but it is not so.
4. Critics feel that if the Sun is the remaining part of the nebula, it should have a bulge in the middle, but it is not so.
5. According to Laplace's hypothesis, all satellites should revolve in the direction of their father planet but it is not so as planets like Saturn and Jupiter revolve in the opposite direction of their father planets.
6. If we accept Laplace's view that planets were formed from the nebula then the planets would have been in liquid state in the initial state and hence would not have been able to rotate around the Sun. Only a solid matter can rotate or revolve along or near the circular path without losing its shape.
7. The British physicist James Clark Maxwell and Sir James Jeans showed that the mass of the rings was not enough to provide the gravitational attraction to form individual planets.
8. According to S.W. Wooldridge and R.S. Morgan, the small degree of cohesion between the particles of nebula would make the formation of ring a continuous not an intermittent process.

SAQ 2

a) Write some differences between inner and outer planets?

b) Where do Asteroids lie? Name the three groups of asteroids.

Spend 5 mins

1.4.2 Dualistic Concept

According to dualistic concept (binary hypothesis), the Solar System originated from two stars. The hypothesis of James Jeans, Chamberlain and Molten, Weitzacker's, and Russell comes under this category.

1.4.2.1 The Planetesimal hypothesis of Chamberlin and Moulton

T.C. Chamberlin, a geologist, in collaboration with Forest Ray Moulton an astronomer, postulated a hypothesis known as 'Planetesimal hypothesis'. According to this hypothesis, the planets originated form Planetesimals. They believed that two big stars i.e. the Sun and a companion star, existed in the universe in the initial stage. The Sun was much bigger than the present Sun and was made of very small particles which were cold and solid. The companion star was moving on its path and while doing so, it came closer to the Sun, and due to the gravitational pull exerted by the star, solar tide accrued and a large number of particles got detached from the outer layer of the Sun. They termed these particles as Planetesimals.

These Planetesimals could not combine with the moving star because by the time they reached it the star had moved ahead on its path and vanished in the space. These Planetesimals were attracted by the proto Sun and started revolving around the Sun. These Planetesimals were of different sizes. The bigger Planetesimals served as the nucleus and attracted the smaller Planetesimals towards them. Gradually the bigger Planetesimals became bigger and became the present planets.

Critical analysis

1. Jeffrey has criticized this hypothesis saying that such big planets cannot be formed by the material ejected from the Sun.
2. The assumption that the increase in the size of the nucleus due to collision of the Planetesimals is not trustworthy.

1.4.2.2 Tidal hypothesis of James Jeans and Jeffrey

It was Sir James who propounded the tidal hypothesis to explain the origin of the Earth in 1919. Later on Harold Jeffery made some suggestions by inclusion of which, the hypothesis became more relevant and significant. According to this hypothesis, the Sun existed as a big mass of gas rotating around its own axis in the universe. Besides the Sun, there existed one more star called the intruding star which was many times bigger than the Sun.

As this star neared the Sun, tides started occurring on the outer surface of the Sun due to gravitational pull exerted by this star. When this intruding star came at its closest point to the Sun the height and the size of the tides increased. As a result, huge amount of matter was ejected from the Sun and a cigar shaped tide filament which was thousands of kilometers in length was created. James Jeans named this ejected cigar shaped matter a filament as it was thicker in the center and thinner at the ends. This filament got separated from the Sun and then came closer to the intruding star but by then the star moved ahead on its path.

Therefore, this filament could neither unite with the Sun nor with the star. This filament then started revolving the Sun due to the effect of gravitation. Due to the gravitational pull and condensation, knots started forming from the liquid matter of the filament. The knotted filament then condensed and formed different planets. Due to the tidal effect, the filament remained thicker in the center and thinner at the ends. Hence the planets formed by this filament are bigger in the center and smaller at the sides.

Characteristics of this Hypothesis

1. If we arrange all the planets in a line, we will see that the bigger planets lie in the center and the smaller at the end. This cigar shaped arrangement supports his hypothesis.
2. The other characteristics of James hypothesis, that the arrangement of the satellites too is cigar shaped, again supports his hypothesis.
3. The smaller planets comparatively took less time to cool, hence these planets either have very less or no satellite at all. The bigger planets remained hot for a longer period, hence they have more satellites.
4. In this hypothesis, it was assumed that all planets originated from the separated filament of the Sun. All planets are made of the same matter which again supports this hypothesis.
5. This hypothesis successfully justifies the fact that all the planets were formed at the same time.

Critical analysis

1. According to the critics like Delevin, in the distance between different stars in the universe is very big. Hence there is a remote possibility of the star coming so close to the Sun that it can be affected by the gravitational force of the Sun.
2. According to Russell, there is no possibility that such a huge amount of material of filament could have come out of the Sun to form planets at such a greater distance.
3. Some scientists are of the view that planets cannot be formed due to the cooling of the gaseous filament. They instead feel that the gaseous filament might have disappeared in the universe due to the prevalence of extremely high temperature values.
4. Many astrophysicists are of the view that the angular momentum imparted by the star to the planet was not high enough to match the existing angular momentum of the planets of our Solar System.

1.4.2.3 Binary Star Hypothesis of Russell

Russell was of the view that there were two stars near the primitive Sun. These are known as the companion star and the approaching star. The companion star was revolving around the Sun. Later on, the approaching star came near the companion star and it too started revolving. The direction of the star was opposite to that of the companion star. Russell assumed that there might have been a distance of 45 to 65 lakh kilometers between the stars. So, the approaching star might have been at a far greater distance from the Sun than the companion star. Hence, there would have been no effect of the tidal force of the approaching star on the Sun. But the companion star would have certainly been attracted toward the approaching star because of the massive gravitational force. As these two stars came closer, the gravitational and tidal force between them increased which created a bulge on the outer surface of the companion star. When the approaching star, came near the companion star huge amount of matter was ejected from it due to the gravitational force exerted by the approaching star. The ejected matter started revolving in the direction of the approaching star i.e. in the opposite direction of the revolution of the companion star. The planets were formed from this ejected matter of the companion star and the satellites were formed from the ejected mater from the planets due to the mutual attraction.

Critical analysis

1. Russell has explained the formation of the planets from the ejected matter of the companion star but he has not explained as to what happened to the remaining portion of the companion star.
2. He did not explain why the planets started revolving around the Sun after the giant approaching star moved ahead on its path.

Spend 5 mins

SAQ 3

Why James Jens did called the ejected matter cigar shaped?

1.4.3 Modern Concept

1.4.3.1 The Nova Hypothesis of Hoyle and Littleton

The two mathematicians named F. Foyle and Littleton of the Cambridge University presented their theory known as Super Nova hypothesis in the year 1946. Their hypothesis was based on nuclear physics. Energy which is emitted by any star in the form of light heat etc. is generated by the process known as nuclear fusion. According to them, the heavy elements played important part in the formation of planets. These heavy elements are formed when atoms of lighter elements combined under intense heat and pressure released vast amount of energy. These heavy elements constitute 90% of the total mass of the planets. The main constituent in the formation of the stars is hydrogen. The planets on the other hand have less than 1% hydrogen. The scientists F. Foyle and Littleton showed that the heavy elements originate even due to the burning of hydrogen. But an ordinary star like Sun can only form an element like helium. The formation of the heavy elements is possible only if the burning of hydrogen takes place at high temperature. Such high temperature is available only in supernova stars. A star becomes supernova star when it is left with very less hydrogen which is not enough to burn. Hydrogen is the source energy which gets converted into helium and generates energy. In the case of scarcity of hydrogen, the star has to shrink in order to produce energy. The speed of rotation of the star increases when it shrinks. The force at the center increases due to high rotational speed. As a result, the star throws out first the lighter matter and then the heavy elements. The formation of the heavy elements in the Universe is possible in this state only. The cosmic light which is many lakh times more than the light of Sun is visible in the center after the heavy metals are thrown at a distance. These stars with such huge light are termed as nova. According to these scientists, the planets have been formed due to the explosion of one super nova star. The explosion of the super nova star generated intense heat equivalent to $5x10^{-9}$ degree celsius which was sufficient enough to start the process of the nuclear fusion. According to them, the two stars present there were the Sun and the super nova star. The distance between these two stars was the same as the distance between the Sun and Jupiter. The explosion of the super nova generated intense heat and pressure from which the primitive Earth was made. Thus, the planets of our Solar System were formed due to the condensation of the matter of the disc form of the matter thrown out of the matter by super nova due to its explosion.

Critical analysis

1. This hypothesis does not support the origin of the pair of stars.

2. It fails to explain the peculiar arrangement of the planets on the basis of their direction of rotation, their size, plain of revolution, path of the planets and the lighter constituent elements of the planets of the outer circle of our Solar System.

1.4.3.2 The Big Bang Hypothesis

This theory was postulated by Limaitre in 1950-60 and validated in 1972. According to this theory, all matter in the universe existed in the form of dense and huge primordial matter. As violent explosion took place in this primordial matter. As a result of which the dust particles present in this matter were scattered in the Universe and formed the present Universe. Based on the new facts of evolution progression of hoyel also theorized the origin of the Universe.

Two Indian scientists namely Govind Swaroop and Vijay Kapahi of Tata Institute of Fundamental Research (TIFR) are also working on this principle of big bang theory. In their view, the Universe originated about 20 billion years ago from the explosion of the big ball of fire which has been formed by the ejected matter of primordial matter. In USA, a model has been prepared to generate the conditions of the big bang theory. The scientists of Berkeley University have used helium balloons to study the micro wave radiation and have supported the big bang hypothesis. Experiment is being carried out by more than 5000 scientists at European Organization for Nuclear Research (CERN in Geneva). These scientists are busy in carrying out research work to generate the condition of huge explosion.

1.4.3.3 Cepheid Hypothesis of A.C. Banerjee

On seeing the star named Delta Cephei Benerjee was inspired to postulate his theory about the origin of Solar System in the year 1942. According to him, some stars in the Universe keep contracting and expanding – This process is called pulsation of stars, and the stars undergoing this process are called Cepheid variable. The group of stars in the universe also contains such stars. The brightness of these stars continuously keep changing. Such systematic change in the light of these stars is the result of the process of contraction and expansion. Once an intruding star happened to pass closer to such Cepheid star, the pulsation in the Cepheid star increased due to the gravitational attraction of the intruding star. As a result, the intruding star attracted enormous amount of the matter of the Cepheid star towards itself. The condensation of this matter forced the planets, the residual part became the Sun. The planet started revolving around the Sun. The intruding star had by then moved far away on its path.

Besides these theories, there are some more theories which have been recently postulated. Among them, a few significant ones are listed below:

- Rossgunn's rotational and tidal hypothesis
- Kuiper's hypothesis (1949)
- Fosenkov's globule concept
- Voitkevich's proto planetary
- Chondrule's concept (1971)
- Jupiter Sun binary system hypothesis of E.M. Drobyshvski

1.5 SUMMARY

Thus, in this unit, you have learnt the following concepts and key themes regarding origin of the Earth in totality:

- Our Solar System consists of a star of average size and luminosity known as the Sun and the planets, their satellites, numerous comets, asteroids, meteoroits and the interplanetary medium etc.
- The planets, most of the satellites and the asteroids revolve around the Sun in the same direction (counter-clockwise), in nearly circular orbits (ellipses but close to circles). When we look down from above the Sun's North Pole, the planets seem to be orbiting in a counter-clockwise direction.
- You have learnt that a new class of dwarf planets was added in 2006. Such planets are confined mostly in the *Asteroid Belt* and the *Kuiper Belt* as well.
- Furthermore, the planets orbit the Sun in or near the same plane called the ecliptic. Scientiest same time calls Pluto as a special dwarf planet in that, and its orbit is the most highly inclined (18 degrees) and the most highly elliptical of all the planets. The Sun contains 99.85% of all the matter in the Solar System.
- You have also learnt that the planets which condensed out of the same disk of material that formed the Sun contain only 0.13 % of the mass of

the Solar System. Jupiter contains more than twice the matter of all the other planets combined.

- The four primary terrestrial worlds are the innermost planets in the Solar System. These are Mercury, Venus, Earth and Mars. There is an additional 8 other terrestrial worlds; the Moon, Io, Europa, Ganymede, Callisto (the four Galilean moons), Titan (a moon of Saturn), Triton (a moon of Neptune) and Pluto. They are called terrestrial because they have a compact, rocky surface like the Earth's and are spherical in shape. The other moons are not spherical and are more asteroid-like (i.e. irregular). Venus, Earth, Mars and Titan have significant atmospheres, the rest have little to zero.
- Jupiter, Saturn, Uranus, and Neptune are known as the Jovian (Jupiter-like) planets, because they are all similar in size and structure, i.e. gigantic compared with Earth and having a non-solid, gaseous nature. The Jovian planets are also referred to as the gas giants. Although, all of them might have small semi-solid cores below their thick atmospheres. A planet revolves around the Sun. A moon or satellite revolves around a planet.
- The term planet or moon is not selected by mass or size of the body (for example, Titan, a moon of Saturn, is bigger than Mercury). The period of revolution of a planet is determined by timing and astrometry (the science of measuring stellar and planetary positions). Periods of rotation are determined by timing surface features, timing clouds or atmospheric features, reflected sunlight (light curves) or Doppler radar measurements of planet limb.

You have learnt and noted that timing of atmospheric features reveals that Jovian planets have differential rotation (meaning their equators rotate faster than the pole regions, i.e. the planet is not solid). Information about the planets is obtained by:

- photometry > temperatures, surface features, albedo
- spectroscopy -> chemical composition
- radar mapping -> surface topology
- space probes -> analyze, survey, sample, magnetic fields
- Solar System Formation:

You have also learnt that any model of Solar System formation must explain the following facts:

- All the orbits of the planets are prograde (i.e. if seen from above the North pole of the Sun they all revolve in a counter-clockwise direction).
- All the planets have orbital planes that are inclined by less than 6 degrees with respect to each other (i.e. all in the same plane).
- All the planets have low eccentricities.
- All planets have prograde rotation except Venus and Uranus.

1.6 TERMINAL QUESTIONS

1. Write five characteristics of the Solar System.
2. Give a critical analyses of nebular hypothesis of the Laplace.
3. Write a short note on Cepheid hypothesis of A.C. Banerjee.

1.7 ANSWERS

Self-Assessment Questions

1. a) Earth's revolution is the complete orbit of the Sun by the Earth. This is called a year and takes 365.25 days to complete.

   b) The change in seasons is caused by the tilt of the Earth's axis to the plane of its orbit, making an angle of c.66.5°. When the northern end of the Earth's axis is tilted towards the Sun, the most direct rays of sunlight fall in the Northern Hemisphere. This causes its summer season.

2. a) The inner planets Mercury, Venus, Earth and Mars are called Terrestrial planets. The outer planets Jupiter, Saturn, Uranus and Neptune are called Giant or Jovian planets.

   b) Asteroids lie in the belt between the orbit of Mars and Jupiter. The three groups of Asteroids are carbon group, stony and metallic.

3. The ejected matter filament is thicker in the center and thinner at the end.

Terminal Questions

1. Refer sec. 1.3 for answering the five characteristics of Solar System precisely.
2. Refer Sub-sec. 1.4.1 for critically analyzing the nebular hypothesis correctly.
3. Refer Sub-sec. 1.4.2 to mention the key idea of Cepheid hypothesis.

1.8 REFERENCES/FURTHER READING

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3. Singh, S. (2012). *Physical Geography*. Prayag Pustak Bhawan, Allahabad.
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UNIT 2

EARTH – A LIVING PLANET

Structure

2.1 INTRODUCTION

In Unit 1, you have learnt about various theories of the origin of the Earth and solar system. As you know, the Earth is the only known planet in the universe that supports life. That is why we also call it the living planet. You have also learnt in Unit 1 that Sun is the main source of energy that drives all forms of life and associated processes on the Earth.

In this Unit, we will focus on the Earth as a living system, its components and their inter-relationships. We begin the Unit about the Earth as a geosphere comprising four major components: **lithosphere, atmosphere, hydrosphere** and **biosphere** (Sec. 2.2). You will learn that all these components function in an inter-related manner, which is useful to support various life forms.

Many natural phenomena and processes occur in the geosphere and their inter-relationship is quite complex, making the Earth a dynamic system. In order to understand these inter-relationships, you must learn the concept of ecosystem that we will discuss in Sec. 2.3. You will also learn about the concept of biomes. While studying Sec. 2.3, you will realize that these inter-relationships are delicately balanced. Any disruption in this delicate balance may lead to serious environmental challenges, such as climate change and pollution etc. You will learn about such challenges and the human response which we have briefly outlined in Sec. 2.4.

In this Unit, you would be acquainted with the components lying **on the surface of the Earth**. In the next unit, you will learn about the **interior of the Earth**, its structure and composition.

Expected Learning Outcomes

After studying this unit, you should be able to:

- describe the components of geosphere namely lithosphere, atmosphere, hydrosphere and biosphere;
- analyse inter-relationship among lithosphere, atmosphere, hydrosphere and atmosphere;
- explain the concept of ecosystem, its structure and functioning;
- define the term 'biomes';
- discuss the implications of environmental challenges due to natural factors as well as human interventions; and
- explain the human responses to ecological challenges.

2.2 The Geosphere

Fig. 2.1 shows a picture of the Earth taken from space. What features of the Earth can you spot in Fig. 2.1? Firstly, you would note that it is **not** a perfect sphere. It is also blue in colour. Do you notice that it has a large water body and landmass? You also know that Earth has an atmosphere, and it supports life.

The name of each sphere has its origin in a Greek word. The Greek word *litho* means rocks, *atmo* means air, *hydro* means water and *bio* means life.

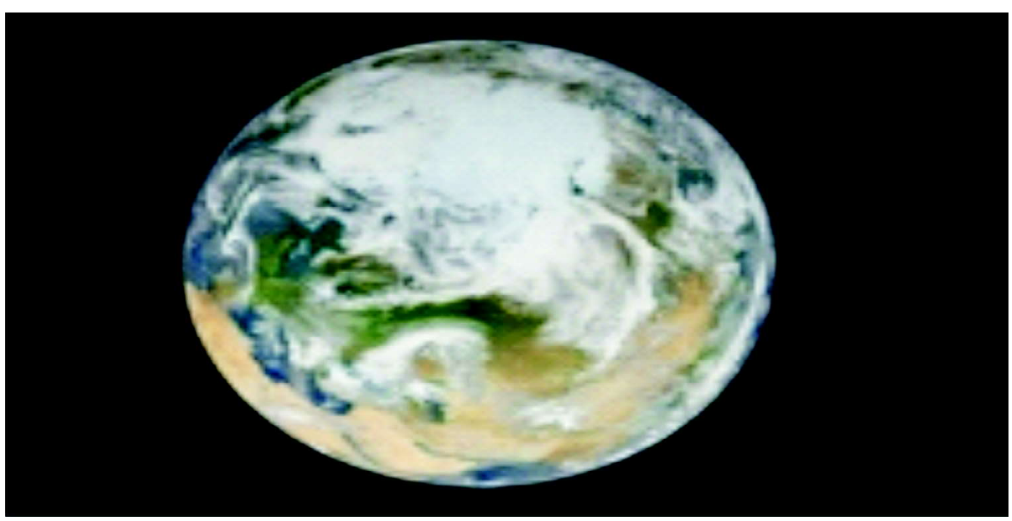


Fig. 2.1: Earth as seen from the space.
[Source: https://visibleEarth.nasa.gov/view.php?id=78349 accessed on October 26, 2018 at 3.30 pm)

Thus, we may think of the Earth as a **geosphere** that has **four** main **components** which are:

1. **Lithosphere** – Solid land mass
2. **Atmosphere** – Envelope of air
3. **Hydrosphere** – Body of water
4. **Biosphere** – All life on Earth

These components of the geosphere are shown in Fig. 2.2.

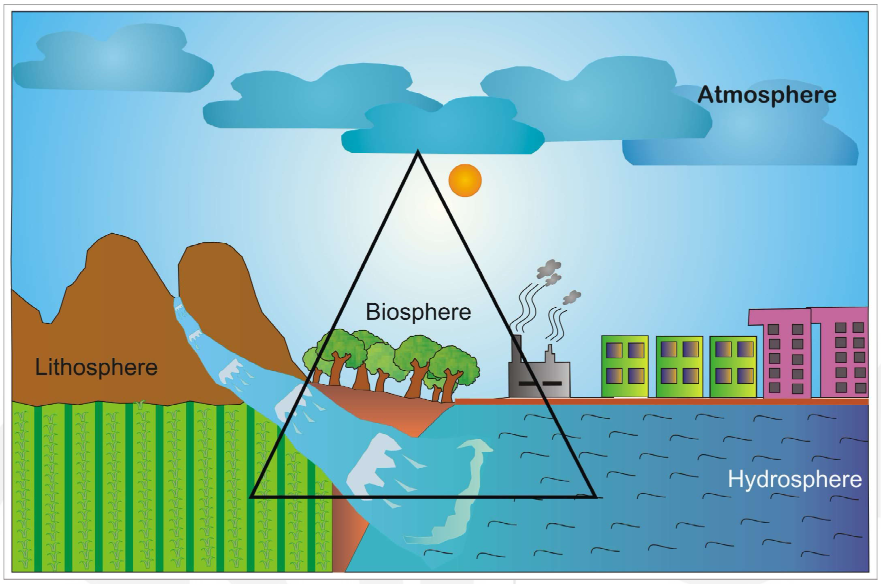


Fig. 2.2: Components of the Geosphere.

Remember, geosphere is a kind of umbrella term exhibiting all these four vital components of the planet Earth. We now briefly describe each one of these components.

SAQ 1

Spend 5 min

Match the following components given in column 1 with their meaning in column 2 of the geosphere? Briefly mention geosphere.

Sl. No.	Components	Meaning
1	Biosphere	Air
2	Atmosphere	Life
3	Lithosphere	Water
4	Hydrosphere	Land

2.2.1 The Lithosphere

Have you ever thought about how various forms of life dwell on the planet Earth? They dwell on the lithosphere which provides suitable and stable piece of landmass. This stable landmass is arranged into several topographical features such as mountains, hills, plains and plateaus etc. Which of these landforms do you dwell on? These landforms make a part of the physical environment in geosphere. The lithosphere provides suitable habitat for various forms of life. It is the source of soil, sediment, salts of the sea and nutrients. It also supports the atmosphere and stores water in its various forms. Hence, lithosphere is necessary and vital for the survival of all flora and fauna along with higher forms of life.

Lithosphere consists of the **crust** and **upper parts of the mantle** (see Fig. 2.3). Crust can be divided into two parts, viz., continental and oceanic crust. You will study and learn in detail about the density and distribution of mantle, core and Earth's crust in Unit 5, Block 2 of this course.

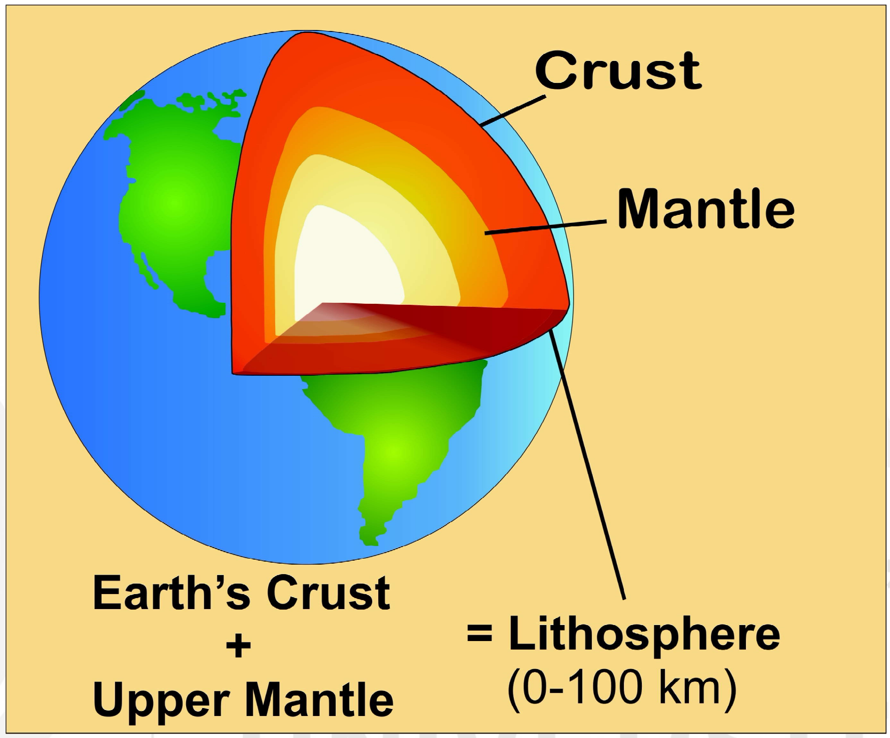


Fig. 2.3: The Lithosphere.

The average thickness of the lithosphere is about 100 kilometres. However, it significantly differs between the oceans and continents. The thickness varies from only a few kilometres over the oceanic parts of the lithosphere to around 300 kilometres under the continents.

Lithosphere is composed of different types of rocks such as igneous, sedimentary and metamorphic rocks. You will learn about lithosphere and its components in more detail in Block 2 of this Course.

Spend 5 min

SAQ 2

a) Choose the correct option.

   a) The average thickness of lithosphere is 300 kilometres /100 kilometres.

   b) Lithosphere is made up of crust/core.

   c) Crustal part of lithosphere covered by oceans is called as oceanic/ continental crust.

d) Lithosphere is the source of soil and sediments/soil and water.

e) Lithosphere is composed of different types of rocks/ different types of gases.

2.2.2 The Atmosphere

The atmosphere is an extremely vital component of the geosphere. You may be well aware that it envelops the Earth and is made up of various gases, water and dust particles. The main gases present in the atmosphere are nitrogen and oxygen having a share of nearly 75 and 24 percent. Many other gases such as argon, $CO_{2,}$ helium and neon are present in minute quantities. The amount of these gases in the atmosphere decreases as we move away from the Earth.

Do you know how far the atmosphere extends beyond the Earth's surface? Almost the entire atmosphere constituting about 97 percent extends upto 30 kilometres from the Earth's surface. Its upper limit is at approximately 1000 kilometres. Try to compare these distances with the diameter of the Earth (12,800 kilometres). The space beyond this distance (about 100 kilometres) is generally referred to as **extra-terrestrial** space. You can refer Unit 10 of this course to understand and learn more about these facts on atmosphere and its composition.

The word terrestrial means 'pertaining to Earth'.

To understand the importance of atmosphere, think about this question. If there would be no atmosphere on the Earth, would life have been possible? The atmosphere plays an important role for the existence of various forms of life. It

- provides air to breathe and water to drink.
- protects all life forms, flora and fauna from the Sun's harmful rays.
- protects us from the meteorites falling from space.
- It is a lively sphere being always in continuous action driven by the solar energy and Earth's rotation.

Thus, we cannot imagine any form of life on the Earth in the absence of this protective layer. We now understand that atmosphere is a dynamic component of the geosphere. It has two types of interactions:

1. Interaction between atmosphere and the other three components of the geosphere;
2. Interaction between atmosphere and outer space.

Both these types of interactions give rise to climate and weather processes, which you will study in Block 3 in detail.

SAQ 3

Spend 5 min

State which one of the following statements are true or false.

a) Atmosphere is a solid landmass.

b) It provides us air and water.

c) It protects us from the meteorites falling from space.

d) It is a part of the crust and upper parts of the mantle.

e) The average thickness of atmosphere is 100 kilometres.

2.2.3 The Hydrosphere

So far, you have learnt about two important components of the geosphere. We now discuss the hydrosphere, which is equally important. Have you ever pondered why Earth is called a blue planet? We call it a blue planet because of the presence of large amounts of water on it. Approximately, three-fourths of the surface area of the Earth lies under water. Water is present in three states gaseous (water vapour in the atmosphere), liquid (running water on the surface and underground water beneath the surface) and solid (ice caps). Water present in the Earth's surface is mainly of two kinds:

- Fresh water (about 3%), stored in the glaciers, lakes, streams and underground.
- Salt water (about 97%), stored in seas and oceans.

Refer to Fig. 2.4, which shows the distribution of water on the Earth.

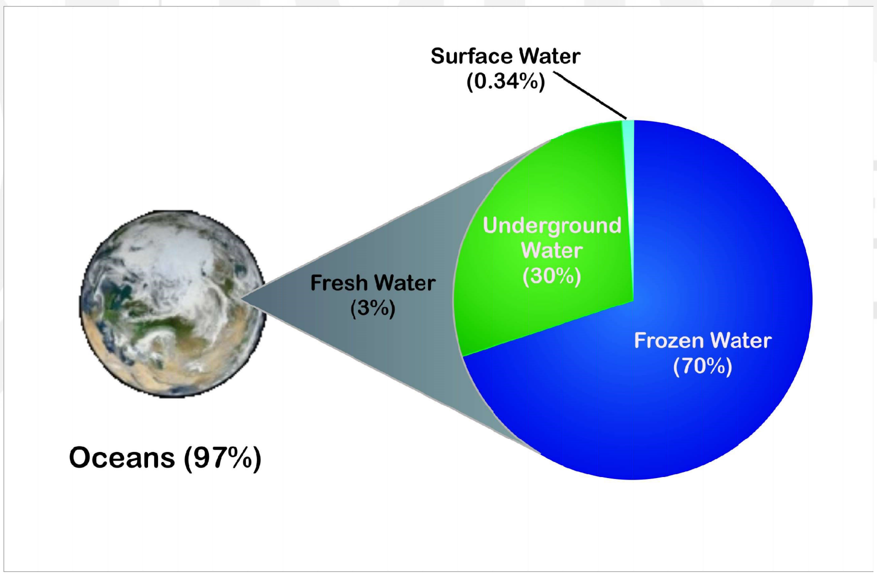


Fig. 2.4: Distribution of water on the Earth.

The cryosphere signifies cold sphere taken from the Greek word '*cryo*' which means cold.

All these forms of water are dynamic in nature. Water is stored in glaciers, lakes, rivers, seas and oceans etc. The sphere which stores enormous amounts of water as ice in frozen state is known as cryosphere (sub-component of hydrosphere). The stored water in its liquid state evaporates into the atmosphere and, falls back in the form of precipitation (rain, snow and hailstorm etc.) on the Earth's surface. Then, it flows back to the various water bodies. This process of **evaporation** and **precipitation** is continuous. It is called the **'hydrological cycle'**. You will learn about it in detail in Block 4 of this course.

Water in oceans, seas, rivers and streams is also responsible for changing and creating various landforms. For example, the rocks on sea beaches are constantly sculptured by water waves resulting into formation of various landforms like cliffs and sea caves etc. Do you know of any such landforms? If so, write them down in the margin. You will further study and learn about water and its role in sculpting the various landforms in Unit 9, Block 2 of this course.

Landforms: The scientific study of landforms is the subject matter of geomorphology which is a part of physical geography.

As you know, water is essential for various forms of life. Even our body is composed of nearly 75% water. The hydrosphere is a source of the huge amounts of water needed for agriculture, industry and other economic activities. You will agree that modern society would not exist in its absence.

SAQ 4

Spend 5 min

State which one of the following statements are true.

a) Freshwater is stored into seas and oceans.

b) Salt water is stored in seas and oceans.

c) Salt water is stored into ponds and lakes.

d) The continuous process of evaporation and condensation is known as hydrological cycle.

e) Freshwater is stored into streams, lakes and glaciers and underground.

f) Hydrological cycle refers to the landforms sculptured by water waves.

2.2.4 The Biosphere

So far, you have learnt that lithosphere, atmosphere and hydrosphere constitutes an integral part of the geosphere. These three are inorganic or non-living components. Now, you will learn about the organic or living component called the **biosphere.** This is the fourth most important and lively component. Therefore, it also includes those parts of the lithosphere, atmosphere and hydrosphere that provide the physical environment.

Can you imagine how the life forms evolved over the planet Earth? All life forms have evolved in a narrow zone in the biosphere. It includes plants, animals and all other living things (Fig. 2.5).

You may think that these life forms are self dependent for their needs of food and water. It is not so. They are not independent as they share complex relationship with the other three components of the geosphere.

For example, the oxygen we breathe is provided by the atmosphere; the water we drink comes from the hydrosphere and the geographic area where we live is on the lithosphere. Thus, together the other three components provide the physical environment that supports all life forms.

You can state that biosphere includes:

- All life forms on the Earth; and
- Those parts of the lithosphere, atmosphere and hydrosphere that provide the physical environment to support life.

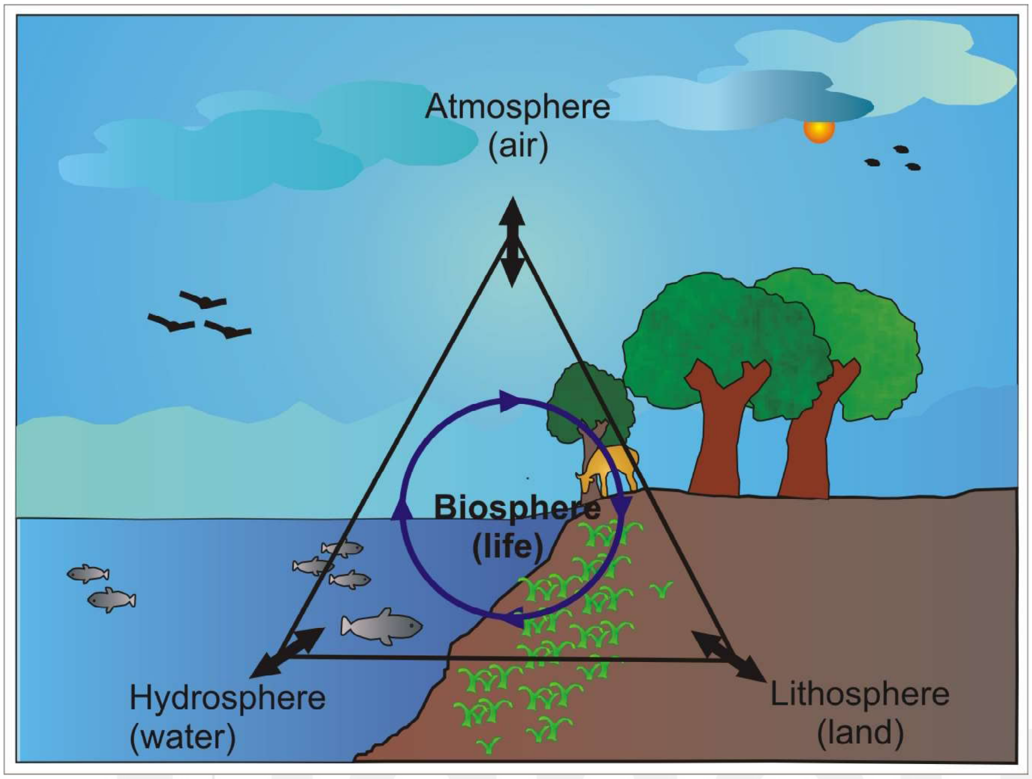


Fig. 2.5: Life Forms in the Biosphere.

You may have noticed that most of life forms are confined to the Earth's surface. It includes all flora and fauna along with human beings.

Life is mostly confined in a narrow zone of the geosphere. It is concentrated between the lowest layers of the atmosphere and the ocean bottoms in the biosphere. More than three-fourths of the all life forms are concentrated here. However, there is an exception to this.

Can you imagine that life forms also develop beyond this narrow zone? Well, it is true. Do you know examples of such life forms? The coral reef that develops in the deep ocean floor is one such example. Another example is bacteria that thrive and live on deep parts of the rock layers beneath the Earth's surface up to 4 kilometres.

We burn fossil fuels (coal, oil and gas) for different purposes such as cooking, transportation and running of factories and industrial units. Burning of fossil fuels adds up carbon dioxide and other gases such like sulphur dioxide and carbon monoxide into the narrow zone of biosphere.

You may refer ***http://cos.arizona.edu/outreach/biosphere-2*** for further information on biosphere.

This additional amount of carbon dioxide may disturb the natural balance in rest of the three components of the geosphere. Such kinds of disturbance may generate harmful effects over the only liveable planet Earth. It may lead to disasters such as climate change, air and water pollution etc. to name a few-with which you are familiar.

One of the best examples of man-made ***'Biosphere'*** in the world is that of '***Biosphere 2'*** located in the University of Arizona, USA. It provides one of the world's most unique facilities dedicated to the research and understanding of global scientific issues.

You can say that all the four components of geosphere namely lithosphere, atmosphere, hydrosphere and biosphere are linked to each other. In other words, all are dependent on each other for the exchange of energy and material. They co-exist and one cannot function without the help of other. You will learn about this dependency and exchange of energy and matter in the next section on ecosystems.

Thus, the biosphere quintessentially regularly alters the character and form of lithosphere, atmosphere and hydrosphere. It is the only lively component that renders a definite purpose to the other three non-lively components. Biosphere is made up of many ecosystems which you will study in the next section.

SAQ 5

Spend 5 min

Fill in the blanks with suitable words and terms.

a) Biosphere is the................most important and..................component of the geosphere.

b) This is the only.................component whereas other three are................ components.

c) It includes....................on the Earth along with parts of the......................, atmosphere and.................that provides the...................to support........

d) Fossil fuels includes .... , ... and..........................

e) Burning of fossil fuels leads to the addition of gases such like................, ...and..............into the narrow zone of...................................

2.3 ECOSYSTEMS

You have already learnt in the previous section that Earth is the only planet in the universe that supports life. You may think that what makes the life possible to develop on planet Earth?

You have also learnt in sub-section 2.2.4 that all life forms develop in a narrow zone. Each of the life form develops in a particular system called as **ecosystem**. The term 'ecosystem' refers to the total assemblage of interacting living and non-living organisms along with their physical environment. Now you are familiar that ecosystem is a part of the biosphere.

Broadly, there are many ecosystems along with their sub-systems (hundreds and thousands) that flourish in the biosphere. All kinds of ecosystem thrive on the exchange of energy and matter within and across other kinds of ecosystems. Have you ever thought that which type of ecosystem do you work or live in? If you happen to work or live in an area surrounded by forests/lakes/ hills/mountains/plains/plateaus/deserts, then you will be working or living in any of these corresponding types of ecosystems.

Every type of ecosystem is characterised by two components: 1) **Biotic or living; 2) Abiotic or non-living.** Both types do exchange energy and matter

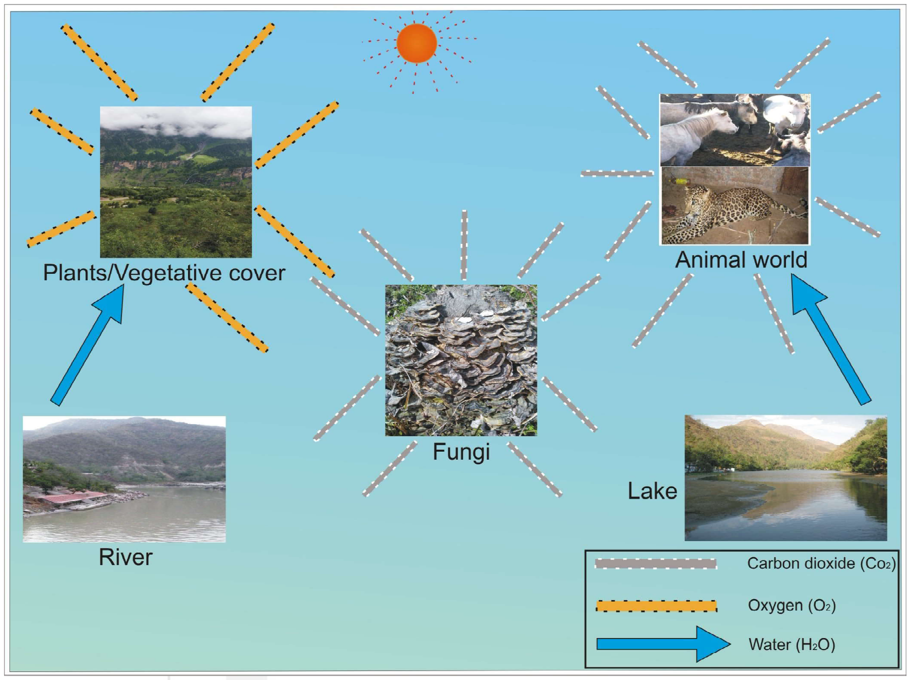


Fig 2.6 : Components of Ecosystem and their Interactions.

along with their physical environment (Fig. 2.6). That is how all the life forms thrives and develops in a given ecosystem in the biosphere.

You can learn this with the example of a green plant. You must be familiar the way green plants derive energy and matter for their evolution. They do so by taking in the sunlight energy in a process called as **photosynthesis**. It is a

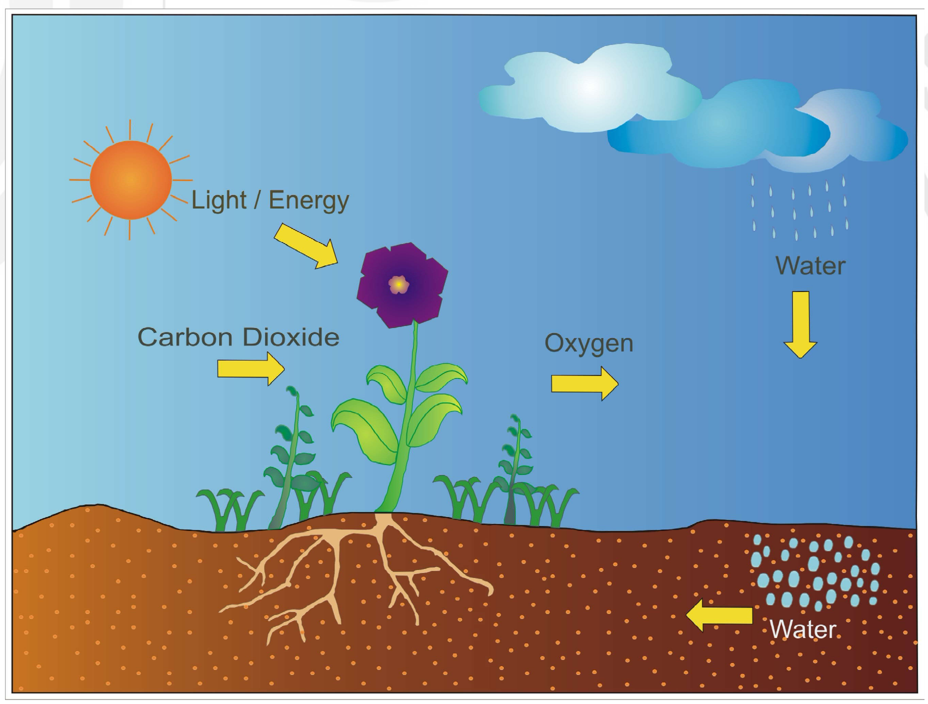


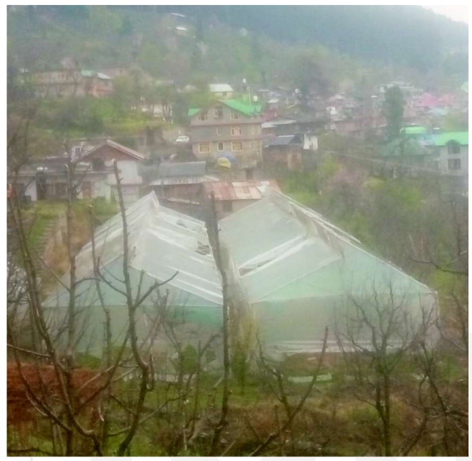
Fig 2.7 : How the process of Photosynthesis works?

continuous process whereby every organism recycles the drawn energy from one part of the ecosystem to its counterparts. Thus, an ecosystem acts as a basic unit of the natural environment (Fig 2.7).

Planet Earth in itself is a big ecosystem. A basic feature of any kind of ecosystem is its openness to enable the seamless flow of energy and material. It is made up of many ecosystems and is of two kinds namely short-term and long-term ecosystems. You can say that the continent or landmass in which your country, state or district is located, is a part of long-term ecosystem. Agricultural fields (rice, wheat, sugarcane, mustard and many others) are examples of short- term ecosystems. Another interesting example is that of a **polyhouse** (exclusive ecosystem), which is an artificially created short-term ecosystem (Fig. 2.8). It is a kind of system that facilitates the cultivation of off-seasonal vegetables, nursery plants (including flowers, vegetables and fruit plants etc.), and flowers round the year irrespective of the climate of a region.

Polyhouse is a kind of artificially created infrastructural facility. It enables the farmer's to grow special kind of flowers, fruits and vegetables along with plant nurseries in a preset environmental set-up round the year irrespective of climatic conditions.

(a)



(b)

Fig. 2.8 a) Indoor view and b) Outdoor view of the Polyhouse.

It is fairly possible that you might have seen the polyhouse in your region, state or country. You can in fact visit the one, if possible, and note down the diverse type of activities going on there.

Ecosystems are made up of many elements. You will study these important elements which makes it the part of the biosphere i.e. biomes in the succeeding sections.

2.3.1 Elements of Ecosystem

Before we discuss the major biomes, we will discuss about the important elements of ecosystem. You are already familiar with the same. It is composed of four elements as given under (Fig 2.9):

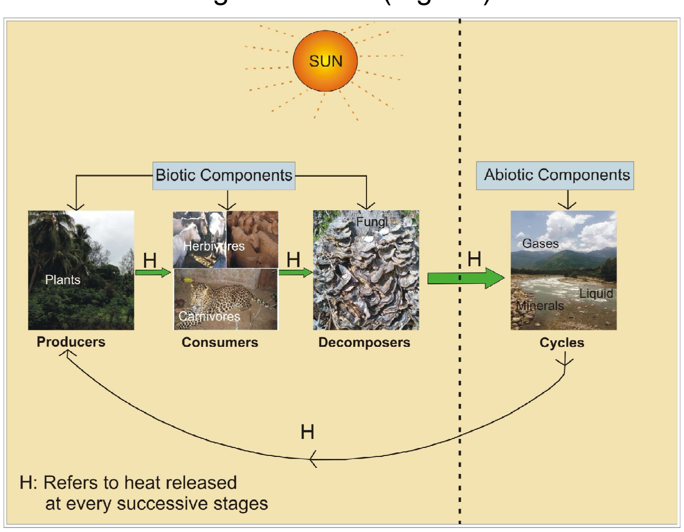


Fig. 2.9: Elements of Ecosystem.

- Abiotic
- Autotrophs or producers
- Heterotrophs or consumers
- Decomposers;

First element of **Abiotic** is a non-living element. Second one is **autotrophs** or producers are the living elements as they derive energy through the sunlight. Third element comprises **heterotrophs or consumers**. They obtain energy from both plants and animal life. Based on their feeding cycle, **heterotrophs** are divided into four groups:

1. **Herbivores** are the first group which thrive on living plant material;
2. Second group is **detrivores** which eat both dead plant and animal material;
3. Third group is called **carnivores** that feed on other animals and;
4. Fourth group is called **omnivores,** which feed on both plants and animal materials.

All three elements along with their sub-elements are crucial to the working of ecosystems.

Fourth element is called **decomposers** that help to rot the organic matter fastly including bacteria, fungi and micro-organisms etc. You may have already seen these elements a number of times in your life, but may not have paid proper attention. Now, you can observe these elements carefully to understand their role and functions in the ecosystem.

SAQ 6

Spend 5 min

Match the following elements given in column 1 with their definition in column 2 of the ecosystem? Briefly mention decomposers

Sl. No.	Column 1 Elements	Column 2 Definition
1	Autotrophs	Non-living
2	Abiotic	Living
3	Heterotrophs	Bacteria, fungi and micro-organisms
4	Decomposers	Obtain energy form plants and animals

2.3.2 Biomes

You have learnt in the previous Sec. 2.3 that ecosystems are made up of both **living and non-living organisms** along with **natural environment**. **Human ecology** is the branch of geography that studies the ecosystems. Ecosystems are concentrated in the major bio-geographical regions called **biomes.** We will discuss the major types of biomes.

The term 'biome' literally means the total assemblage of flora and fauna that can survive in a given geographical area. An ideal condition for their survival is provided by the diversity of natural environment. For instance, you can think about the type of natural vegetation that grows in your area. Do you know how that particular type of vegetation develops and survives in a given geographical region?

All kinds of natural vegetation which you see are dependent as well as closely interlinked with the type of soil and fauna. These two factors themselves are dependent on the climate and natural environment of an area. There are several types of biomes such like tropical rainforests, mountain and desert biomes. Each type of biomes may contain several ecosystems adapted within each of these.

Did you know that which kind of biome your natural surroundings belong to? You can try to associate by referring the Table 2.1.

Table 2.1: Type of Biome and their Description

Sl. No.	Types	Description
1	Tropical Rainforest	Characterised by dense forest and heavy rainfall
2	Savanna	Widespread grasslands in the tropics
3	Desert Biome	Plants, animals and soil of very dry regions
4	Temperate grassland	Mid-latitudinal grasslands
5	Temperate forest	Mid-latitudinal woodlands
6	Tundra	Cold, treeless regions in the arctic circle
7	Polar	Perpetually ice covered regions
8	Wetlands	Fresh or salt water logged area
9	Mountains	Elevated area

These are the main and broader types of biomes. Each and every kind of biome may contain one or more than one kind of ecosystems. Now, you can observe and relate the kind of ecosystem in which you dwell upon belongs to forest, desert or mountain biome. These biomes are utilized by human beings to carry out economic activities since ancient times. Earlier, their needs were basic and the population densities were also minimal characterised by agro-pastoral societies.

These two factors led to the optimum utilization of natural resources extracted from variety of ecosystems and their corresponding biomes. Natural resources such like **fossil fuels** (coal, oil and natural gas), minerals, water and land resources are very important for human beings. You will certainly agree that human societies may cease to function in their absence. There used to be a harmonious relationship between man and environment particularly corresponding with pre-industrial revolution period.

> Third world refers to the underdeveloped areas.

However, this harmonious balance started witnessing drastic changes corresponding with the onset of industrial revolution during 1850s in Britain. Gradually, by the end of 19^{th} century, it covered almost the entire World barring the parts of **'Third World'**. Industrial revolution was coupled with the population explosion that led to reckless urbanisation. This directly led to the increase in the growth of million plus (a city with more than million people's) and other cities and towns which you may be living in or have seen in your country or elsewhere. You may be aware of the various kinds of problems in urban areas either in your state/country/continent. Can you list few major problems (e.g. pertaining to environmental, social and economic) and their causes of any urban centre which you know or are familiar of?

Many of such pertinent and interrelated issues of resource utilization, over-utilization and conservation will be discussed in the next section. The main purpose here is to sensitise you and the prospective learners' about these contemporary issues. You will agree that today's learners may become tomorrow's wheel turner for the society and economy alike. Provided, if they are satisfactorily sensitised and trained to practice the educational ethos, and put into effect the same into their daily actions, lives and society alike. This may help to ensure and lead to the definite route for the judicious utilisation and conservational efforts of precious natural resources found over the only liveable planet Earth.

You will further learn about the concepts of biome and ecosystem in details in fourth semester course on 'Environmental Geography' of your bachelor's degree programme.

Spend 5 min

SAQ 7

Match the following elements given in column 1 with their description in column 2 of the biomes?

Sl. No.	Types	Description
1	Tropical rainforest	Fresh or salt water logged area
2	Savanna	Perpetually ice covered regions
3	Desert biome	Mid-latitudinal woodlands
4	Temperate grassland	Mid-latitudinal grasslands
5	Temperate forest	Plants, animals and soil of very dry regions
6	Tundra	Elevated area
7	Polar	Widespread grasslands in the tropics
8	Wetlands	Characterised by dense forest and heavy rainfall
9	Mountains	Cold and treeless regions

2.4 ENVIRONMENTAL CHALLENGES AND HUMAN RESPONSES

You have learnt in the section 2.3.2 that human beings extract diverse natural resources from a range of ecosystems. This process of resource extraction leads to natural imbalances due to mismatch between supply and demand requirements. Thus, this aspect leads to the generation of many environmental challenges. You must be familiar with some of the environmental challenges which your district, state or country is facing. If you do so, can you list some of these here?

There are several environmental challenges in today's world. You must have noticed that humankind is grappling with many environmental challenges in modern times. These could be of various scales ranging from local, regional, national and international dimensions. To list few important ones, which you may be already familiar of are as under:

- Climate change
- Shrinking of glaciers
- Water, land and air pollution
- Ozone depletion
- Deforestation
- Soil erosion
- Haphazard urbanisation
- Desertification
- Unsafe disposal of industrial, toxic and urban wastes etc.

Such issues and challenges have generated a scholarly debate across the disciplines of scientific inquiry in the world.

Furthermore, such challenges seems to be acquiring an alarmingly ascending order corresponding with the ever-increasing population densities across the geographic regions. You may have seen or read in the newspapers/magazines about such instances and their possible causes quite often. Can you mention any two kinds of pertinent issues being faced by the denizens of your locality or state/country?

To counter these challenges, therefore, nations or human societies are trying to evolve clean and suitable mechanisms by combining both the age-old traditional mechanisms and scientific knowhow. The prime objective is to minimise the damages caused by both natural and anthropogenic hazards. It is also kept in mind so as not to harm the naturally occurring substances or more appropriately natural resources found over the **planet Earth**. In this background, you will study some of the prominent factors concerning these issues in the following sections of this unit.

2.4.1 Hazards and Disasters

You have learnt in the section 2.4 about the environmental challenges and human responses. In this section 2.4.1, you will learn about the hazards and disasters. Literally, hazards and disasters refer to the kind of disastrous influences being caused by either natural agents or anthropogenic activities in a geographic region. The most prominent among the natural agents are Earthquake, volcanoes, landslide, flood and tsunami etc. List of natural agents are numerous and hence, it is suggestive only here. If you are enthusiastic about this, then you can check a complete list and explore the same in detail by visiting these government websites **www.nidm.gov.in and www.ndma.gov.in.**

Many of you may recall the devastating Earthquake of 2001 in Bhuj, Gujarat and recent flash floods of 2013 in Uttarakhand and 2014 in Jammu and Kashmir, 2018 and 2019 in Kerala and Himachal Pradesh. And, all of you must have heard and noticed the occurrence of recent catastrophic super-cyclone named '***Fani'* (which means hood of a snake)** that hit the Odisha and neighbouring state of West Bengal in May 2019. It is recorded that these natural disasters caused immense losses including natural wealth, property, human and animal lives and infrastructural amenities such as buildings, roads and bridges etc.

One of the best examples of human response to cope up and significantly minimize the losses from natural hazards particularly inflicted to human lives is sucessfully shown by the Odisha Government during the attack of recent super-cyclone '*Fani*' in 2019. The amount of loss to human lives was tremendously brought down owing to the scientificaly induced timely and efficient implementation of the pro-active measures (a lesson which they learnt from the losses caused by the super-cyclone in 1999). It has attracted the praise from the United Nations (UN). Such good and robust practices can be emulated across the vulnerable geographic region to minimize the multitude of losses from the natural hazards and disasters respectively.

Hazards and disasters may also be triggered by anthropogenic activities. It may be of several kinds. Do you know of such type of hazards and disasters? You can broadly say that following activities may induce these as under:

- Overexploitation of natural resources like fossil fuels and water
- Overgrazing and unscientific agricultural practices
- Overpopulation, unscientific industrialisation and reckless and un-planned urbanisation etc. to name a few.

There are lot of examples of succesful human responses to counter the anthropogenically induced hazards and disasters. Prominent among these are chipko movement, apiko movement, chilka movement and many others in our country. You can explore and read about these to educate yourself. The impetus given to the 'Swachh Bharat Abhiyan (2014-19)' in order to generate awareness and active response concerning the environment across the strata of society by the Prime Minister of India is one of the best examples. Another latest single-handedly driven call to champion the cause of climate change that ushered into mass-scale awareness and generated active response among the childrens and adults around the World concerning the fatal consequences on our planet Earth by a Swedish school girl 'Greta Thunberg' as an environmental crusader is a well known example.

You may agree that both sets of agents may together carry the potential to evoke an irreparable damage to the environment. Damages of such colossal nature may jeopardise the aspirations of future generations. It seems that in the name of modern economic development, human beings are trying to aggravate the environmental problems than the anticipated course of development. All these issues and challenges related with the environment have direct relationship with the factors of human population size, which you will study in the next section.

2.4.2 Human Population Dimensions

You have studied about hazards and disaster in the previous Sub.sec. 2.4.1. It taught you that these two are governed by the population dimension to a considerable extent, which you will learn in this part. You will agree that every second or minute or next, human population dimension is just mounting at an alarming rate as a whole on planet Earth. There are interesting instances of human population dimensions and human factors. These two are directly related and exert immense pressure on the twin concepts of environmental challenges and human ecological responses. For example, there are geographic regions which have extremely narrow population densities and exert correspondingly low to very low pressure as in the remote villages of Indian Himalayas on the one hand. On the other hand, most of the geographic regions have extremely higher population densities and correspondingly high to very high pressure as in the fertile Indo-Gangetic river plains of India. You will subscribe to this view that these two extremes also correspond with the optimum and over utilisation of natural resources.

You can visualise and compare these two extremes in terms of a remote village and a metropolitan city. A remote mountainous village will have very thin population and may exert minimum damage to the natural resources on the one spectrum. On the other spectrum, a metropolitan and million plus city as well may cause and inflict number of environmental damages which may sometimes assumes alarming proportions. For instance, all of us know in general that most of the Indian metropolitan cities such like Delhi, Mumbai, Chennai and Kolkata are grappling with the ever-increasing imbalance between the availability of resources and population dimensions. The problems of this imbalance can be seen manifesting into air and water pollution, haphazard urbanisation resulting into poor characterisation of both economic and living space. Also, the traffic snarls at peak working hours during morning and evening, safe disposal and management of solid waste material are other acute problem areas.

This is just a suggestive list for you to get sensitised about the type and scale of the issues and challenges concerning the planet Earth. You may be familiar with such instances. One of such instance is from the 'Delhi pollution control committees' recent orders to close five restaurants in the ***'Garden of Five Senses, New Delhi'*** as these eating units were draining the raw urban waste into nearby streams (HT, Friday 28th Feb, 2014). Recent phenomenon of acid rain in urban areas is important fallout due to air pollution. And, more recently, the alarming levels of air pollution in National Capital Region, Delhi (NCR) and elsewhere as well in India has put the human beings (especially more so the juveniles and old population) under severe health risk. It is right time for the government agencies to enact a set of facilitative policies rather than imposing barriers only. You will agree that the enactment and effective implementation of policies may help to tackle and counter the multitude of socio-economic and environmental problems.

2.4.3 Environmental Impact Assessment (EIA)

The term environmental impact assessment (EIA) denotes a technique in Earth sciences. It tries to assess the positive and negative impacts of developmental activities that may be thrust upon the natural environment. For instance, it may include cutting of trees, overuse of fossil fuels, modernization and mechanisation (high yielding variety seeds, chemical fertilisers and overuse of water for irrigation and machinery) of agriculture, reckless industrialization and urbanisation and so on. Can you think of any such developmental activities in your surroundings? If yes, then try to note down the same.

These developmental activities may vary in their size and dimensions from small scale industries to large scale industrial or multi and trans-national projects. Natural environment has its own mechanisms of natural adjustments known as 'Homeostatis Mechanism' whereby nature or planet Earth replenishes itself from the after-effects of all sorts of natural, economic and other developmental projects thrust upon it. However, you may be aware that with the passage of time, such harmonious balance has been disturbed to a colossal extent that may jeopardise the aspirations of future generations. EIA is a kind of tool that tries to assess the impact of developmental projects on different aspects including environmental and socio-economic etc. beforehand. You will further explore and learn it in detail in your fourth semester course on Environmental Geography.

2.4.4 Adaptation and Sustainable Livelihood

The perception of ecosystem based sustainable adaptation is itself suggestive of its meaning. It indicates that any kind of spatial avocations should be strictly based on the judicious, optimum or sustainable utilisation of natural resources drawn from a particular ecosystem. All economic activities should be carried out in mutual harmony with nature so as to strengthen the practice on the concept of ecosystem based sustainable adaptation to cope up with the impacts of climate change.

You may agree that adoption of such kind of approach may promote and enhance the conservation and managment of natural resources and contribute to the betterment of environment and society alike.

2.4.5 Thinking Environmentally

This concept directly relates and confirms to an old dictum given by ‘Mahatma Gandhi’. It states that the mother Earth has everything to satisfy the needs of everyone but not the greed. It means that the human civilisations across the geographic and administrative regions, culture and societies should practice this dictum over the only inhabitable planet Earth. For example, most of you may already know that tribal people such as ‘***Andamanese and Sentinelese’*** living in the Indian group of Islands and ***‘Santhal and Birohar’*** tribal groups residing in the parts of eastern India live in close harmony with nature. There are several examples of such harmonious relationships that exist between humans and their environment. Alongside, you can also explore such cases in different geographical regions to understand their ecological, socio-cultural, religious, economic and medicinal dimensions which may be of utmost importance.

You will learn about the harmonious concepts of man-environment relationship in detail in the second semester course on Human Geography of your bachelor programme. In other words, the human beings need to think environmentally and should leave an ecologically sound footprint emerging out of social, religious, political and economic activities rather than random, chaotic and unsound footprints. Human beings should keep in mind the fact so as not to digress the aspirations of future generations.

You can say that thinking environmentally reinforces the previously described concept of ecosystem based sustainable adaptation in Sub. sec. 2.4.4.

2.5 SUMMARY

Thus, in this unit, you have studied and learnt the following key points, concepts and issues as under:

- Geosphere is an umbrella term that denotes four vital components namely lithosphere, atmosphere, hydrosphere and biosphere of planet Earth.
- Lithosphere is the place where we live and carry out our economic and spatial activities.
- Atmosphere provides us all the necessary elements vital for our survival such as air and water along with protection from Sun's rays and falling meteorites from the space.
- Hydrosphere makes us available the entire water resources like fresh, frozen and saltwater for different purposes.
- Finally, the fourth important component of biosphere unlike other three components is the only live component. You have learnt that all life forms thrive in this thin layer.
- You have also learnt the concept of ecosystem along with its dynamic and diverse nature. It is the most basic and important unit of natural environment. It represents the total assemblage of living and non-living organisms along with their physical environment.
- Interactivity between all four components has made you learn that no single component can survive on its own. Thus, it is a closely interwoven mesh of interactions and interconnectedness that supports the various processes and drives all forms of life on the planet Earth.
- In recent times, due to tremendous increase in population, all four components have started witnessing numerous changes leading to challenges. Challenges such as climate change, pollution, landslide, floods and many others have assumed alarming proportions. You have learnt that how human beings are struggling with environmental challenges and at the same time are developing the human response to counter these.
- As a whole, you have learnt in brief about the planet Earth along with its components, their inter-relationships and environmental challenges and human responses.

2.6 TERMINAL QUESTIONS

1. Define atmosphere and highlight its significance.
2. Write a short note on concept of ecosystem by citing suitable examples.
3. Define the term 'Environmental Impact Assessment' (EIA).
4. What do you understand by the adaptation and sustainable livelihood and thinking environmentally? Illustrate?

2.7 ANSWERS

Self-Assessment Questions

1. Biosphere = Life, Atmosphere = Air, Lithosphere = Land, Hydrosphere = Water. Geosphere includes all of these four components.

2. a) Average thickness of lithosphere is 100 kilometres.

   b) Lithosphere is made up of crust.

   c) Crustal part of lithosphere covered by oceans is called as oceanic crust.

   d) Lithosphere is the source of soil and sediments. e) Lithosphere is composed of different types of rocks.

3. b 4. b and e

5. a) Biosphere is the fourth most important and lively component of the geosphere.

   b) This is the only living component whereas other three are non-living components.

   c) It includes all life forms on the Earth along with parts of the lithosphere, atmosphere and hydrosphere that provides the physical environment to support life.

   d) Fossil fuels include coal, oil and gas.

   e) Burning of fossil fuels leads to the addition of gases such like carbon dioxide, sulphur dioxide and carbon monoxide into the narrow zone of biosphere.

6.

Sl. No.	Column 1 Elements	Column 2 Definition
1	Autotrophs	Living
2	Abiotic	Non-living
3	Heterotrophs	Obtain energy form plants and animals
4	Decomposers	Bacteria, fungi and micro-organisms

Decomposers consists of bacteria, fungi and micro-organisms etc. They help to rot the organic matter fastly.

7.

Sl. No.	Types	Description
1	Tropical rainforest	Characterised by dense forest and heavy rainfall
2	Savanna	Widespread grasslands in the tropics
3	Desert biome	Plants, animals and soil of very dry regions
4	Temperate grassland	Mid-latitudinal grasslands
5	Temperate forest	Mid-latitudinal woodlands
6	Tundra	Perpetually ice covered regions
7	Polar	Cold and treeless regions
8	Wetlands	Fresh or salt water logged area
9	Mountains	Elevated area

Terminal Questions

1. Your answer should cover the meaning of atmosphere and its importance. You can refer to Sub-sec. 2.2.2.
2. While answering this question, you should be able to aptly define the meaning of ecosystem as a basic unit of environment. Your answer should broadly cover the way exchange of matter and energy takes place across the ecosystem. You can refer to sec. 2.3.
3. Your answer should be able to define the term Environmental Impact Assessment (EIA) along with its application. You can refer to Sub-sec. 2.4.3.
4. In your answer, you should be able to cover the key tenets of adaptation and sustainable livelihood along with thinking environmentally. In doing so, you can discuss the diverse economic activities by citing suitable examples. You can refer to Sub-sections 2.4.4 and 2.4.5.

2.8 REFERENCES/FURTHER READING

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UNIT 3

INTERIOR OF THE EARTH: STRUCTURE AND COMPOSITION

Structure

3.1 INTRODUCTION

In Units 1 and 2, you have learnt about various theories of the origin of the Earth and Solar System and Earth as a living planet. As you learnt, that many theories gave different logic for the origin of the Earth. You have also learnt in Units 1 and 2 that Sun is the main source of energy which drives all forms of life and associated processes over the Earth's surface and beneath it as well.

In this Unit, we will focus on the interior of the Earth, its structure and composition. We begin the unit with basic concepts related to our planet Earth by explaining Earth as a **solid body, Earth's interior**, the **rock cycle** along with **layers and discontinuities** (Sec. 3.2). You will learn that all these concepts are inter-related with each other that forms a complex network of Earth's interior processes, structure and composition.

Earth's interior structure and composition are characterised by its thermal and physical state. In order to understand these, you must learn about its thermal and physical state which we will discuss in Sec. 3.3. While studying Sec. 3.4, you will learn about few important theories propounded by different Earth scientists. You will realize that seismology plays a pivotal role and provides a scientific basis to study the Earth's interior. You will further learn about the intricate relationship between these two in Sec. 3.5.

By and large, in this unit, you have been introduced to the **Earth's interior, its structure and composition**. In the next Unit, you will learn about the **Concept of Isostacy**.

Expected Learning Outcomes

After studying this unit, you should be able to:

- describe the basic concepts, namely, Earth as a solid body, Earth's interior, rock cycle along with layers and discontinuities;
- illustrate the thermal and physical state of the Earth's interior;
- explain the Earth's internal structure as propounded by different Earth scientists;
- Define the concept of seismology and Earth's interior.

3.2 BASIC CONCEPTS

As we know that basic concepts form the backbone of any field of study across the disciplines of studies or branches of knowledge. You will agree that the learning of basic concepts not only provides a sound understanding of the phenomenon under study but also acts as a source for further learning.

3.2.1 The Earth as a Solid Body and Earth's Interior

Earth consists of various layers or a solid body and is thought to be assembled with area/group of rocks and other materials. The Earth as a solid body or layer collectively means an area of rocks. You may recollect the details of the Earth's lithosphere which you studied from Sub-sec. 2.2.1 in Unit 2. Do you know that approximately 16 kilometres beneath the Earth's surface, more than three fourth of Earth's matter is composed of rock materials. Basically, the study of rocks is the domain of petrology (which is part of geology). It deals with the rock system which is made up of unique or aggregates of mineral matters. It is this mineral matter that helps to build the Earth's crust.

> You may refer and watch a small documentary film titled 'Earth 101' at https:// nationalgeographic.com/ science/space/ solar system/ earth and explore relevant online resources for further information on plant Earth and its interior parts.

Earth's interior is arranged into three layers namely crust, mantle and core. In simplest words, you may visualize it with the peeling off process of a boiled egg. The outer hard and thin layer may resemble to the crust, middle layer to the mantle and inner layer to the core respectively. The most common and reliable source to study the Earth's interior is **Seismology** which you will learn in Sec. 3.4. Let us study the rock cycle which is exclusively the domain of geologists. They study the Earth's history, structure and composition in detail. Geographers are required to know the basic properties of rocks also.

3.2.2 Rock Cycle

You can think of any continuous activity. For example, four distinctive weather seasons in a year namely spring, summer, autumn and winter and many others such like nutrient cycle, carbon cycle, hydrological cycle or sowing and harvesting of wheat, rice or mustard etc. on every successive agricultural year. In similar ways, rock cycle refers to the constant organization and reorganization of various rock types found over the **Earth's Crust** i.e. **lithosphere**. You can understand this with the following example as shown in Fig. 3.1.

Soon after the process of solidification of magma and lava, **igneous rocks** are formed. You can visualise it in terms of a walls of the building soon after the process of cementing during construction. Rock materials comes from the Earth's middle inner layer i.e. **Mantle** through volcanic eruptions. After the formation, igneous rocks become exposed to the **agents** of **weathering and erosion** on the Earth's surface. These agents break the igneous rocks into small pieces. Further, the **agents of denudation,** for example **wind** (aeolian) and **water** (fluvial) transports these small rock particles and deposits into the seas and oceans. You will learn about these in Units 8 and 9, Block 2 of this course in detail.

Have you ever wondered that what happens to the small rock particles after these gets accumulated? This process of continuous accumulation deep into the sea floor, in due course of time, transforms it into new sedimentary rocks as shown in Fig. 3.1.

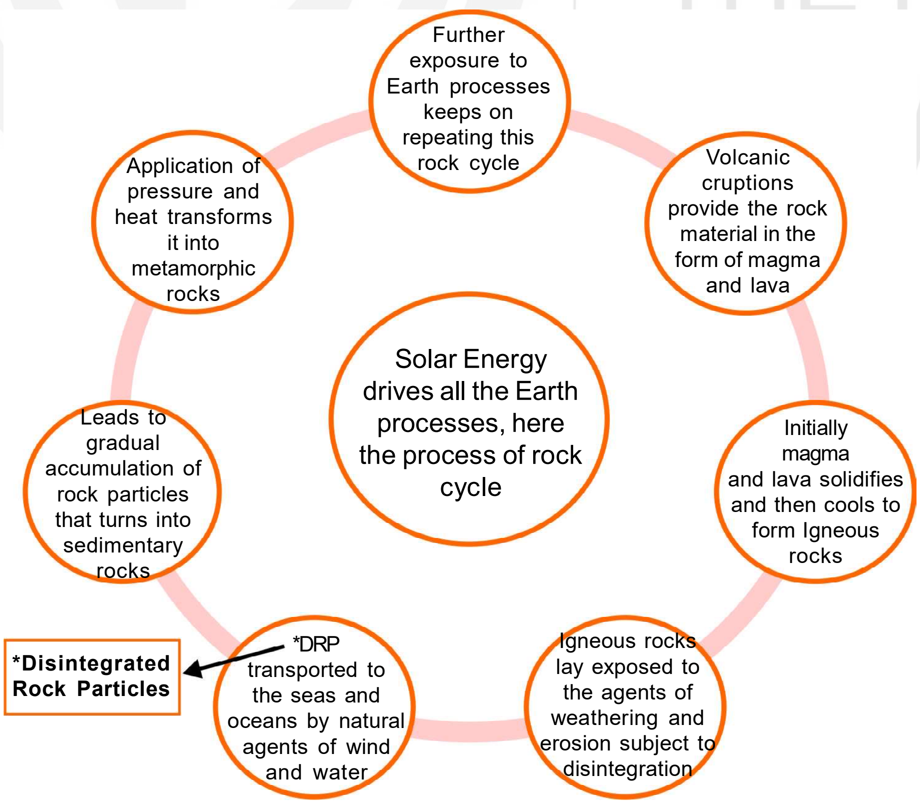

Fig. 3.1: Rock Cycle.

Have you ever thought that how metamorphic rocks are formed? Metamorphic rocks are formed by the application of pressure and heat. When metamorphic rocks lay exposed, it may also worn away to transform into sedimentary rocks and so on with the passage of time. The process of rock cycle is never ending. Most of the rock material is constantly recycled matching both formation and disintegration of rocks found over the Earth's crust.

3.2.3 Layers and Discontinuities

You may be amazed to know the way distinctive and complex system of layers and discontinuities do exist in the rock cycle. One of the most reliable sources of information about the Earth's interior layers comes from the precise study of seismic waves. You are quite familiar with the same as these are nothing but simply waves that generates tremors resulting into Earthquakes. Seismic waves could be either natural or artificially stimulated one in a preset/ modulated environment. Based on the speed of seismic waves, three main layers along with discontinuities have commonly been recognized. These are crust, mantle and the core layers. Seismic waves could be of two kinds i.e. surface and body waves. Further, these three main layers are divided into sub-layers on the basis of changing speed of the seismic waves. You will learn about all these layers and their discontinuities in Sec. 3.4 of this unit in detail.

Spend 5 mins

SAQ 1

Explain the concept of rock cycle?

3.3 THERMAL AND PHYSICAL STATE OF THE EARTH'S INTERIOR

You may wonder that what do we mean by the thermal and physical state of the Earth's interior. It signifies the study of three vital parameters namely temperature, pressure and density etc. All of these parameters are responsible for the generation of present state of the affairs and may also shape the future development both at over the Earth's surface and in the Earth's interior parts too.

Scientific analysis of all three parameters would enable you to comprehend the underlying details of the Earth's interior. Afterwards, you would be able to study the dynamics of the Earth's interior in a better way.

3.3.1 Temperature

As understood, you must be familiar with the meaning of temperature. All of you will agree that to live and sustain in a given type of environment/place/ space or geographic region, all kinds of flora and fauna along with human beings will require a threshold temperature value. You will be surprised to know that temperature increases with increasing depth. Similarly, you will further uncover that temperature increases with increasing altitude on the Earth's surface in Block 3 on **Climatology** of this course.

On an average, the temperature increases at a rate of 1° C for every 32 metres as one goes deep inside the Earth's interior. At this rate of temperature rise, the core layer of the Earth is expected to witness temperature values of around 4000° C. You will be amazed to know that temperature is likely to vary from 1200-2000° C at this rate deep at 48 kilometres into the **asthenosphere**. You will agree that at such a high range of temperature values, the underlying rocks along with their mineral constituents may alter their shape, structure and properties altogether. You can witness this change from solid to varying degrees of liquid state in various kinds of minerals along with their constituents.

Threshold value means the value at which a given substance or material attains the optimally required value.

For this reason, you will wonder that the source of volcanic eruptions is considered to be at a depth of 48 kilometres inside the Earth's interior. But, it is only true for first 8 kilometres of depth inside the Earth beyond which it is very difficult to gauge the temperature values. Temperature values keep on progressively declining at far greater depths beyond 100 kilometres. Reason for this is the gradual decline in the availability of two heat sensitive radioactive minerals of uranium and thorium respectively (Singh, S. 2012).

3.3.2 Pressure

You might be getting curious about the cause for such high density of the Earth's core layer. Traditional view stated it to be the heavy pressure of the rock strata succeeding each other. It is well understood fact that the overlying pressure from rock layers simply increases the density of rocks. It further increases with the increase in depth.

However, this opinion is not entirely true since the density of a given rock types have ***threshold value*** beyond which the density ceases to increase. Thus, the factor of overlying pressure cannot alone increase the density of rocks to greater extent lying underneath the lithosphere. This inference leads towards the fact that the core layers of the Earth could be made up of intense metallic matter having inherently very high density. However, scientific studies have clearly set out the fact that the core layer of the Earth is constituted by two heavy metallic components of iron and nickel. It has also been confirmed based on the geocentric magnetic field of the Earth's interior. A layer of crystalline rock strata encircles the topmost portions of the metallic core of the Earth.

3.3.3 Density

On an average, the density of the Earth's interior is 5.5. However, it is 2.7 in the continental shells i.e. upper surface layers which consist of granitic rocks and sial i.e. silica and aluminium. It is also believed by the Earth scientists, particularly geologists that the density of material increases directly in proportion to the depth. In other words, you can say that the density of materials increases as one goes down into the Earth's interior parts.

You will be amazed to know that the density of materials found in the core layers of the Earth are around dozen times denser compared to the water. Iron and nickel together known as 'nife' forms the core layer of the Earth's interior.

The density is 4.3 in the middle layers composed of sima i.e. silica and magnesium. Apparently, heavier the material, the density will also be correspondingly high.

SAQ 2

Spend 5 mins

Briefly discuss the temperature, pressure and density conditions of the Earth's interior.

3.4 EARTH'S INTERNAL STRUCTURE: THEORIES

A number of Earth scientists propounded various theories regarding the Earth's internal structure. Few important ones are discussed below for you to have a broader idea regarding the same.

3.4.1 Edward Suess

His theory deals with the chemical properties of the Earth's interior structure. He said that a thin sheet of sedimentary rocks having extremely small thickness envelops the Earth's crust. It is made up of crystalline rocks with silicate as a mineral. Two most important minerals are mica and feldspar. Light silicate matter makes up its upper portion whereas heavy silicate matter determines its lower portion. This scholar categorised the Earth's internal structure into three zones as discussed below.

i) **The Sial:** Sial is made up of two words i.e. **Si plus and Al** which denote silica and aluminum. It lies beneath the outer sedimentary envelop of the Earth's internal structure. On an average, its density is 2.9 and varies from 50 to 300 kilometers in its thickness. This layer is characterized by the surplus availability of acid materials along with silicates of potassium, sodium and aluminum etc. Major structural parts of the planet Earth i. e. continents are created on sial layer.

ii) **The Sima:** A layer situated just below the sial is known as 'sima'. It is constituted by the basalt material. Sima is the only provider of magma and lava resources blown up from volcanoes during active phases. It is composed of two words **Si plus and Ma**, whereby **Si** stands for silica and **Ma** for magnesium. Hence, silica and magnesium are two important minerals. Average density varies from 2.9 to 4.7. Its thickness varies from 1000 to 2000 kilometers respectively. This layer is characterized by the availability of plenty of base materials including those of calcium, iron and magnesium silicates etc.

iii) **The Nife:** It is placed beneath the middle layer of sima. Nickel (Ni) and ferrium (Fe) are two dominant minerals. Nife has very high density because of the dominance of heavy metals. Its thickness is 6880 kilometers. Availability of iron i.e. **ferrnium** shows two properties of firmness and magnetism.

Suess has divided the Earth's internal structure into three layers of sial, sima and nife with one or more than one common characteristics.

3.4.2 Van der Gracht

He has categorized the Earth's interior into four layers. Diverse properties of the same have been described in Table 3.1.

Table 3.1. Earth's Interior Layers According to Van der Gracht

Sl. No.	Layers	Thickness	Density
(i)	Outer sialic	60 kilometres below Continents 20 kilometres below Atlantic Ocean Not present below Pacific Ocean	2.75 – 2.9
(ii)	Inner silicate mantle	60 – 1140 kilometres	3.1 – 4.75
(iii)	Zone of mixed metals and silicates	1140 – 2900 kilometres	4.75 – 5.0
(iv)	Metallic nucleus	2900 – 6371 kilometres	11.0

Source: Singh, S. 2012, *Physical geography*.

His scheme indicates the Earth's internal layers with varying figures regarding the number, thickness and density properties etc. As opposed to this scheme, most of the Earth scientists distinguished a universal pattern that deals the Earth's internal structure into three layers as discussed below:

i) **Lithosphere:** It is mostly made up of granitic rocks with a thickness of 100 kilometers. Silica and aluminum are the major minerals. Average density of lithosphere is 3.5.

ii) **Pyrosphere:** Basalt is the main constituent mineral. Thickness of this layer is 2780 kilometres and average density is 5.6.

iii) **Barysphere:** Iron and nickel are the two important minerals. This layer spans for nearly 200 kilometers to the core. Average density varies from 8 to 11.

3.4.3 Arther Holmes

A. Holmes categorised the Earth's internal structure into two major layers i.e. upper and lower layers. Upper layer has been named as crust. Sialic layer propounded by E. Suess and top parts of sima forms this layer. Substratum is the name given to the lower layer. It is made up of the lower portions of E. Suess's sima layer. Thickness of sial lies underneath the continental shell. He outlined four characteristics of the Earth's internal structure as below:

i) Thermal conditions – 20 kilometers or less

ii) Surface seismic waves (I waves) – 15 kilometers or more

iii) Longitudinal waves – 20 to 30 kilometers

iv) Subsidence of the deepest geosynclines – 20 kilometers or even more.

As like other scholars, he has also confirmed to the earlier theories. But, he gave rather incomplete theory of the Earth's internal structure. Since, it has been recognized and categorized into three distinctive layering systems known as **crust, mantle** and **core** respectively.

SAQ 3

Highlight the major key points of various theories.

Spend 5 mins

3.3.4 Seismology

Seismology is a kind of scientific endeavour akin to medical profession. It studies the Earth's internal structure with the help of tremors including both the Earth tremors and nuclear outburst etc.

You will be surprised to know that it is not a new idea as science of 'Seismology' was prevalent since ages. It was practiced in ***'Asian giant land of China'*** around 2000 years before to determine the direction and source of seismic waves.

A Chinese scholar named '***Chang Heng'*** was the first to devise an instrument used to detect the unfelt and guess the direction to the epicentre of Earthquakes during 132 A.D. (Lutgens et. al, 2011). Seismographs used in contemporary times are testimony, which resembles to this old Chinese instrument.

You can see that how this instrument looks like and functions in Fig. 3.2. Did you notice the freely suspended hanging weight from a flat support base? The

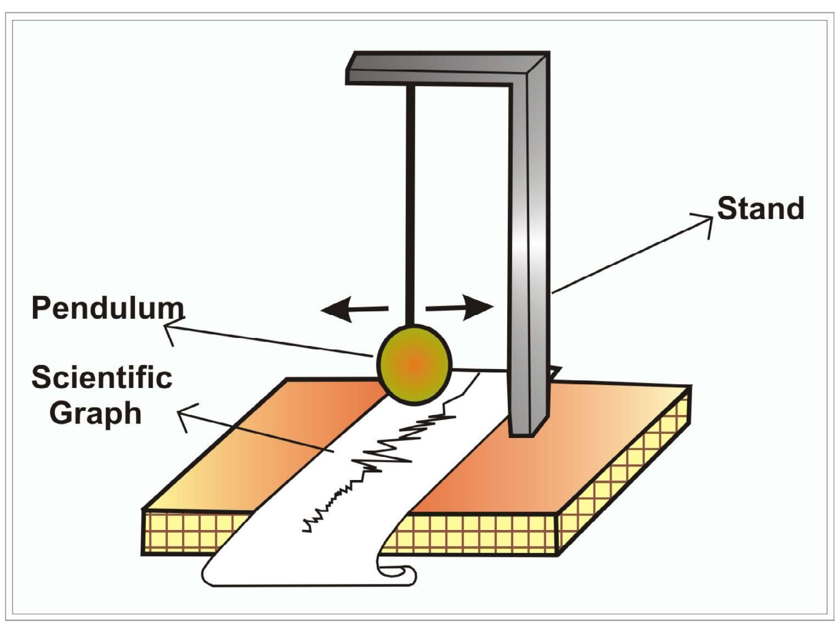

Fig. 3.2: Illustration of Seismograph.

moment seismic or Earthquake tremors hit the seismograph; it remains static owing to the factor of inertia of weight. It is relative to the moving objects of support and the Earth's surface. In other words, you can say that factor of inertia of weight keeps the dormant objects at dormant state whereas dynamic objects at dynamic state.

A seismograph that collects the evidence regarding the nature and types of Earthquake tremors are known as seismograms. It tells us about the main types of tremors produced due to the movement of rock strata. For instance, the continuous movement of ***tectonic plates*** (i.e. concept of plate tectonics dealt in detail in Unit 5, Block 2 of this course) of the world in relation to each other which you will learn.

'Tectonic plates' refers to the division of Earth's crust or lithosphere into seven major and almost dozen minor plates including '***continental'*** and '***oceanic plates'***.

There are two categories of **seismic waves** known as **body** and **surface waves**. Body waves moves along the internal division of the Earth and further divided into two sub-types. These are **primary** and **secondary waves** designated by the capital letter **P** and **S**. Surface waves as the name itself indicates moves at the external division of the Earth's surface with two sub-types namely **Rayleigh** and **Love waves**.

1. **Body waves:** Medium of motion through dominant objects is the main characteristic feature of body waves at greater depths. Body waves are of two types viz; **P** and **S** waves. Among this, **P** or primary waves are the speediest moving at a speed of 5 kilometres per second. It is basically push and pull type waves moving towards the direction of wave motion as shown in Figure 3.3 a and b. This resembles to the sound produced by the strings of a musical instrument like sitar as it puts the air into motion to produce such sounds.

   All three medium of atmospheric elements including solid, gas and liquid shows resistance to change in volume at the moment compression is applied. Thus, these medium would eventually come back to their original state once the compression forces are withdrawn. Thus, **P** waves are able to move through all three mediums.

   Next type is **S** waves, which causes vibrations at right angles in the direction of wave movement. It is less speedy than **P** waves as it moves at nearly 3 kilometres per second. You can understand it by taking a 2.5 metre long piece of soft plastic garden pipe. Now, if you tie one side of a pipe over a vertical pole and vibrate it from the free side.

   You will notice the action in a pipe coming from the wave direction as **S** waves transform the form of a conveying substance altogether as opposed to P waves which momentarily does so. In other words, fluid materials such as liquid and gas are not stress tolerant which readily transforms the form of a matter. It means that fluids will not let the **S** waves pass through.

2. **Surface waves:** You will learn that every category of seismic wave has its own unique qualities of motion. This category is characterised by complexity in motion at ground level as evident from Fig. 3.3 c and d. It makes everything upon the surface to be in motion including buildings, bridges, transmission lines and numerous man-made objects. It has two types.

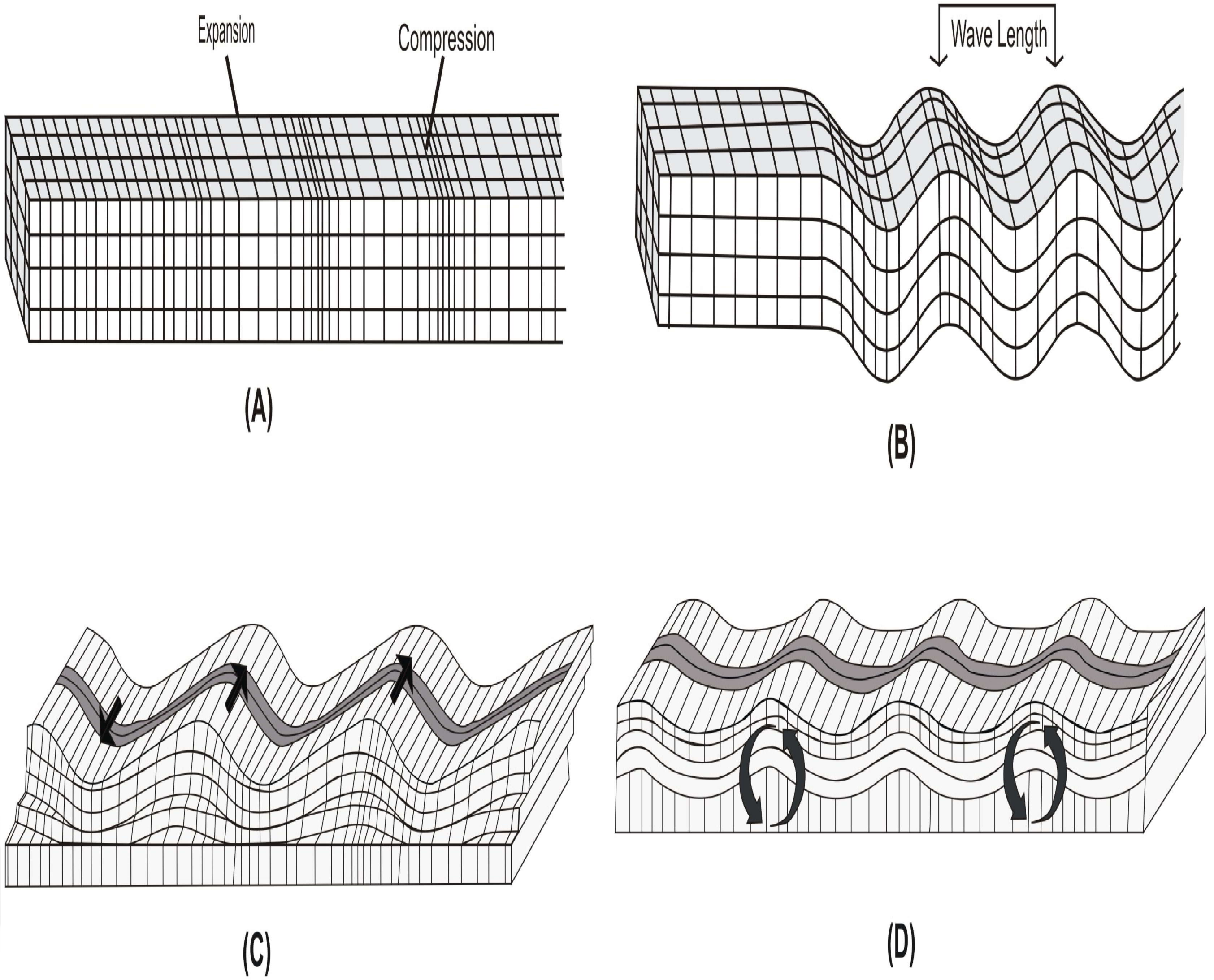

Fig. 3.3: Different Categories of Seismic Waves.
(a) P Waves (b) S Waves (c) Love Waves (d) Rayleigh Waves.

First one is ***'Rayleigh wave'*** with up and down motions as like that of an electronically operated lift in a multi-storey building. Second type is known as '*love wave*' characterised by side to side motion resembling to that of a wave generated by a swiftly flowing ***perennial river system***. Former type is considered more fatal than later as it carries the potential to damage the very base of man-made infrastructural amenities.

'Perennial river system' refers to a river system having permanent flow of water like most of the Glacier fed Himalayan rivers.

You will be aware that it has always been difficult to probe deep into the Earth's interior parts since ages. One of the plausible medium is through the light penetration. But, light cannot penetrate the solid and liquid intervening rock layers found beneath the Earth's surface. Another medium could be either through drilling (e.g. to ascertain the availability of petroleum resources as being done in the Western coast i.e. Off the coast in Bombay High, India) and digging (e.g. to obtain the iron ore mineral as being done in gold mines at Kudremukh Ore Mines, in ***Chikkamagaluru*** district, ***Karnataka,*** India) techniques into the deep interior parts of the Earth to locate various mineral resources.

You will be surprised to know that it is nearly impossible to drill beyond specific depths, roughly 12.5 kilometres, so far. The reason for this is primarily because of prevailing extremely high temperature and pressure conditions existing therein. You may wonder that every year, planet Earth experiences hundreds of tremors which are recorded by the seismographs.

Thus, it is possible through the medium of recording of huge natural tremors that spans the Earth along with seismic waves. These helps us to unravel the mysteries of the Earth's interior segment. A seismic wave takes images of the Earth's interior. You can understand this phenomenon as like that of an image taken by the x-ray, city scan or ultrasound machines for the affected parts of a human body to ascertain the exact reasons of debility and sickness for treatment.

You will learn that due to the seismic wave's complex movement, the study of recorded wave data by seismograms becomes difficult. Not following a direct movement, seismic waves tend to behave differently. They reflect, refract and diffract in their course of movement during tremors as shown in Fig. 3.4.

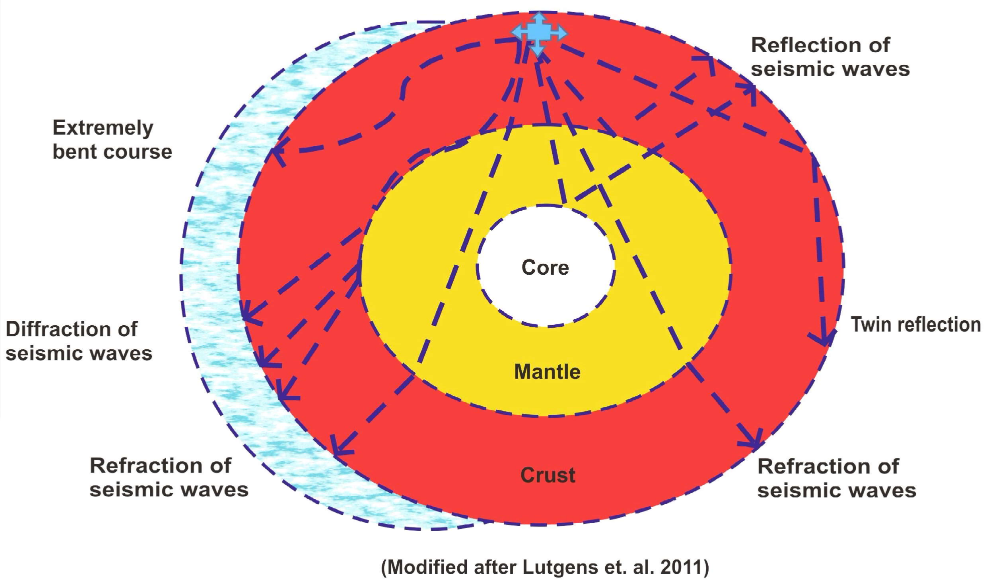

Fig. 3.4: Complex Movements of Seismic Waves in the Earth's Interior.

You will be amazed to know that the junction of two intervening rock layers provides the platform to reflect seismic waves. They also refract in their course from one to another rock layers. Besides, seismic waves also get diffracted while facing any kind of natural/physical barriers like rivers and mountains etc. You can say that it is because of this shifting behavioural characteristic of seismic waves which facilitates the Earth scientists to determine the boundaries found in the Earth's interior parts.

You will further learn that seismic waves follow a much curved movement on account of rising speed directly in proportion to the growing depth. Its velocity accelerates if a rock layer through which it travels is not easily compressible and hard as well. In turn, these two features of a rock layer namely compressibility and hardness allows the investigation of composition and temperature conditions too.

SAQ 4

Explain the term seismology.

Spend 5 mins

3.4.5 Earth's Interior

Thus, based on the study of seismology, Earth's interior can be divided into three main layering systems as shown in Fig. 3.5.

1. Crust

Crust is the outermost layer. It is also known as 'lithosphere' mostly made up of basalt rocks. It has two parts namely upper and lower crust. Mean thickness is around 20 kilometres. Average density of the upper crust is 2.8 whereas it is 3.0 in case of the lower crust.

Little variation between the two is on account of the pressure caused by the superincumbent weight. You will also learn that minerals of the upper crust were formed with lesser pressure compared to the lower crust. Seismic waves lose their speed gradually both in the upper and lower parts of the crust.

2. Mantle

You will be surprised to know that Mantle is characterised by the abrupt rise in the intensity of Earthquake waves. It is known as **'mesosphere'** located at the boundary between lower crust and upper parts of the mantle.

Speed of seismic waves is 6.9 kilometres per second at the base of lower crust. It rises rapidly to 8.1 kilometres per second due to the discontinuity. It lies between the separation zone of lower crust and upper mantle.

This zone of separation was discovered by Yugoslavian seismologist named *Andrija Mohorovicic* during 1909. Thereafter, it came to be known as ***'Mohorovicic Discontinuity'*** or ***'Moho Discontinuity'***.

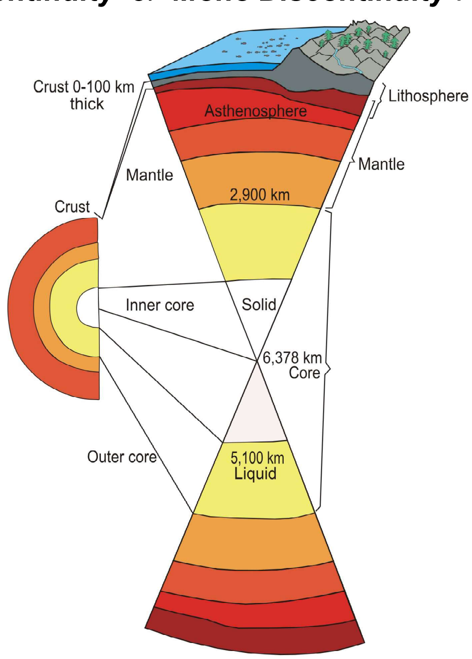

Fig. 3.5: Earth's Layering System.

It has mean density of 4.6 g/cm^3. Beneath the Earth, the mantle spans nearly for a depth of 2900 kilometres. As a whole, it comprises 83 percent of the entire dimension as well as 68 percent of the overall accumulation of the Earth's surface. However, the mantle falls short in its thickness which is less than half of the Earth's radius of 6371 kilometres.

You will learn that earlier mantle was divided into two zones on the basis of varying speed and density of the Earthquake waves. These are **upper mantle** that extends from the ***'Moho Discontinuity'*** further down to a depth of 1000 kilometres and **lower mantle** from 1000 to 2900 kilometres.

Presently, the mantle has been divided into three zones based on the facts from the discovery of the *'International Union of Geodesy and Geophysics'* ***IUGG***. These zones are as under:

i) Moho Discontinuity to a depth of 200 kilometres

ii) To a depth of 200 to 700 kilometres

iii) Depth of 700 to 2900 kilometres

Top region of the upper mantle is characterized by gradual decrease in the speed of Earthquake waves. It extends for a depth of 100 to 200 kilometres i.e. 7.8 kilometres per second. This is known as the zone of 'low velocity seismic waves'.

You will learn that Mantle is rich in silicate minerals like iron and magnesium etc.

3. CORE

You will come to know that **Core** is the deepest and absolutely remote zone in the Earth's interior. It is also known as **'barysphere'**. Extent of core is located at a depth of 2900 kilometres from lower parts of the mantle to the Earth's centre at a depth of 6371 kilometres.

It is marked by the boundary known as ***'Weichert-Gutenberg Discontinuity'*** between lower mantle and upper parts of the core. This is located at a depth of 2900 kilometres.

You will be surprised to know that it is this discontinuity that marks the rapid change in the density from 5.5 g/cm^3 to 10.0 g/cm^3. It is also supported and denoted by the rise in the speed of primary seismic waves at 13.6 kilometres per second.

You will further learn that density of the core increases proportionately with increase in the depth. It becomes 12.3 to 13.3 and then 13.6 respectively. Core layer surpasses the mantle in its density by almost double amount. But, as far as the quantity and accumulation are concerned, it has relatively lower figures of the same having 16 and 32 per cent of the planet Earth.

You will be further surprised to know that at a depth of 5150 kilometres, **Core** has two divisions of **outer and inner core**. Outer core denotes the loss of secondary seismic waves and thus tells us about its molten state. Boundary of inner core goes down from 5150 kilometres up to the Earth's centre situated at a depth of 6371 kilometres. It is in solid state having density figures of 13.3 to 13.6. Primary seismic waves pass at a velocity of 11.23 kilometres per second through the inner core layer.

The **Earth scientists** particularly **geophysicists** and **geochemists** consider the core to be made of metallic materials such as iron and nickel.

SAQ 5

Discuss briefly about the Earth's internal structure.

Spend 5 mins

3.5 SUMMARY

Thus, in this unit, you have studied and learnt the following concepts, key points and issues as highlighted below:

- You have learnt the basic concepts like Earth as a solid body, Earth's interior, rock cycle, seismology and distinctive layering systems along with discontinuities and characteristics as well.
- You came to know that the most prominent discontinuities of ***'Mohorovicic discontinuity'*** lies between crust and mantle and that of ***'Weichert-Gutenberg discontinuity'*** marks the boundary between lower mantle and upper parts of the core.
- You have learnt about the various theories like E. A. Suess, V. D. Gracht and A. Homes etc. dealing with the Earth's internal structure.
- You have also learnt about atmospheric and other variables such as temperature, pressure and density etc. along with their characteristics.

In nutshell, you have learned about the Earth's interior structure and its composition. This information will definitely serve as a key and fundamental to further probe the same in more scientific ways.

3.6 TERMINAL QUESTIONS

1. Describe in short the basic concepts pertaining to the interior of the Earth?
2. What do you understand by the mantle layer of the Earth's interior? Explain?
3. Write down a detailed account of any one theory of the Earth's interior?

3.7 ANSWERS

Self-Assessment Questions

1. Rock cycle refers to the constant organization and reorganization of various rock types. Soon after the solidification of magma and lava, igneous rocks are formed. Igneous rocks break into small pieces by the agents of weathering and erosion. Wind and water carries rock particles into the sea and oceans. It eventually transforms into new sedimentary and metamorphic rocks (application of pressure and heat) as well after accumulation. Rock cycle keeps on repeating.

2. Heavy pressure of the rock strata succeeding each other leads to high pressure which further increases with the increasing depth. Heavy pressure cannot alone increase the density of rocks to greater extent. It could be due to the presence of intense metallic matter having inherently very high density. Core layer is constituted by two heavy metallic components of iron and nickel. It has also been confirmed on the basis of geocentric magnetic field of the Earth's interior.

3. A. Holmes has categorised the Earth's internal structure into two major layers i.e. upper and lower layers. Upper layer has been named as crust. E. Suess's sialic layer and top parts of Sima forms this layer. Substratum is the name given to the lower layer. It is made up of the lower portions of E. Seuss's sima layer. He defined thickness of sial into four categories below the continental shell. He gave rather incomplete theory of the Earth's internal structure. Since, it has been arranged into three distinctive layering systems.

4. Seismology is a kind of scientific endeavour to study the Earth's internal structure. It does so with the help of tremors including both the Earth tremors and nuclear outburst etc. Seismographs gathering the evidence regarding the nature and types of Earthquake tremors are known as 'seismograms'. It tells us about the main types of tremors produced due to the movement of rock strata.

5. Crust is the outermost layer which is also known as 'lithosphere' mostly made up of basalt rocks. It has two parts of upper and lower crust. Mean thickness is around 20 kilometres. Average density of the upper crust is 2.8 whereas it is 3.0 in case of lower crust. Seismic waves lose their speed gradually both in the upper and lower parts of the crust.

Terminal Questions

1. In your answer, you should be able to not only describe the basic concepts pertaining to interior of the Earth, but also should cover the main tenets behind the same. You can refer to section 3.2.
2. Your answer should cover the mantle and its main features. You can refer to section 3.4.
3. While answering this question, you should be able to define the main doctrine behind the chosen theory to discuss the interior of the Earth. Your answer should cover and highlight the key points, strengths as well as weaknesses compared to other theories. You can refer to section 3.6.

3.8 REFERENCES/FURTHER READING

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UNIT 4

CONCEPTS OF ISOSTASY

Structure

4.1 INTRODUCTION

In the previous units of this course, you have learnt about the origin of the Earth, its internal structure and composition as well as the life forms it supports. You must have realized that it is a very complex system. Now we turn our attention to understand how and which features of the Earth helps in achieving this delicate balance. In particular, this unit is devoted to the discussion of isostasy, which gives us information about the mechanical stability between the upstanding features and low lying basins of the Earth. In this unit, we will trace the evolution of the concept of isostasy, which originated in a survey initiated to determine the shape of the Earth.

You might have visited different places in India as well as abroad and observed some relief features present on the Earth's surface, such as mountains, plains, plateaus, valleys, lakes and oceans etc. You might have also noticed that such features are of different shapes and sizes. Do you like to make a list of these for your state? All of these are standing on the Earth's surface as they are balanced by gravity. At times, this balance gets disturbed due to violent Earth movements happening inside the Earth and tectonic disturbances which leads to natural disasters like Earthquake, volcanic eruption, and tsunami etc. Human societies have had witnessed such events through ages. The most recent examples are glacial lake outburst (GLOF) at Kedarnath in 2014 and the Nepal Earthquake of April 25, 2015. These had caused immense loss of life and property. The Gujarat Earthquake of 2001 and tsunami of 2004 had also unleashed huge losses to energy and caused destruction which is still fresh in our memory.

We begin our journey to understand the details of isostasy by discussing the basic principles in Sec. 4.2. It is possible that you are familiar with some of these from your elementary science courses. Yet, we have included these in brief for completeness. This discussion will be followed by the development of the concept of Isostasy. In particular, you will learn about the determination of latitudes and isostatic effects on plate tectonics, ice sheets and sea level changes. Finally, in Sec. 4.4, you will learn about the various explanations about Isostasy. In the next unit, you will learn about material of the Earth's crust and various forces including endogenetic and exogenetic.

Expected Learning Outcomes

After studying this unit, you should be able to:

- explain the term isostasy and discuss the basic principles of isostasy;
- trace the evolution of the concept of isostasy; and
- describe the theories of isostasy based on the principle of buoyancy, the concept of equilibrium and the isostatic adjustments.

4.2 BASIC PRINCIPLES

The word "isostasy" is derived from Greek word meaning 'equal standing", iso means equal, stasis means standing.

Before going to the basic principles, you should learn a bit about the term isostasy. It refers to the study of the dynamics of the outer parts of the Earth that helps to determine the surface elevation depending on the mean density of the underlying rock strata. It is believed that the surface of the Earth moves up and down as surface (or sub-surface) loads are added to or subtracted from it. In a broad sense, it means that the ***Archimedes' principle of buoyancy*** applies to such changes. The dynamic balance between the lithosphere and the asthenosphere is known as isostasy. This term implies that the Earth's gravity causes segments of the lithosphere to shift upward or downward according to their densities. This essentially implies that wherever equilibrium exists on the Earth's surface, the mass above the surface will be balanced by an equal mass below it in the same area. The first hint of isostasy was obtained during middle of the eighteenth century, when the length of a degree of latitude at the equator was measured. This exercise was part of a major project carried out to determine the shape of the Earth. Initially, it was believed that the Earth is a perfect sphere. But subsequent experiments suggested that it could be a prolate oblate spheroid, as shown in Fig. 4.1.

(b) Spheroid

(a) Prolate

Fig. 4.1: Shape of the Earth (a) Prolate Spheroid; (b) Oblate Spheroid.

If the Earth was a prolate spheroid, a degree of latitude would be shorter at poles than at equator. But for an oblate spheroid, a degree of latitude would be greater at poles. Let us now understand how Earth scientists arrived at this conclusion. The initial experiments conducted in Peru (now Ecuador) in South America showed that the Earth is oblate. During these investigations, latitudes measured based on the position of stars and those based on a spirit level or plumb bob showed a difference. This observation was explained as an effect of Newtonian gravitational attraction between the plumb bob and the Andes Mountain; the mountains pulled the plumb bob sideways away from the astronomical vertical direction. On closer examination, this explanation didn't quite work; the calculated deflection of the vertical was too large. In other words, the calculated Newtonian attraction of the mountains was too large. The most logical explanation for the excessive attraction was obtained when it was realised that the deep rocks of an underlying "mountain root" were less dense than the surrounding rocks at those depths. A similar deficit of horizontal attraction was also noted for the Himalayas during geodetic surveys in India during the nineteenth century. Analyses of these data led to the two classical views of isostasy, the '***Airy's hypothesis and Pratt's hypothesis'.***

SAQ 1

Define Isostasy.

Spend 5 mins

Now, let us learn about one of the most fundamental concepts used to understand the relief features of the Earth. It is known as ***Archimedes**' **principles of Buoyancy***.

4.2.1 Principle of Buoyancy

In your 10+2 classes, you must have read and learnt about the principle of buoyancy. Can you recall it? It states that an upward force exerted by a fluid opposes the weight of an object immersed in it. This upward force is called the **Buoyant Force**. If we immerse an object in a container full of liquid, you will notice that the submerged object experiences greater pressure at the bottom of the container than at the top. This difference in pressure pushes the object upwards. This is because the pressure increases with depth as a result of the weight of the overlying fluid. The magnitude of this force is proportional to the difference in the pressure between the top and the bottom of the container, and (as explained by **Archimedes'** principle) is also equivalent to the weight of the displaced fluid. It is for this reason that an object whose density is greater than that of the liquid in which it is submerged tends to sink. You will learn more about the other acting principle of density in the next section.

4.2.2 Density

As we know that buoyancy and density are co-related. We will go into more details of density, as how density affects buoyancy. Let us understand this through a simple experiment. Take a container of water and immerse an object in it. You will observe any of the following three things as stated below:

- The object floats
- The object neither floats nor sinks
- The object sinks

In the first case, the weight of the object is less than the weight of the displaced liquid when fully submerged. In other words, the object has an average density that is less than the fluid and when fully submerged will experience buoyant force greater than its own weight.

In the second case, the object has exactly the same density as the fluid, and its buoyancy also equals its weight. It will remain submerged in the fluid, but it will neither sink nor float. Although a disturbance in either direction will cause it to drift away from its position.

The third case has an object with a higher average density than the fluid .It will never experience more buoyancy than the weight and it will sink. A ship will float even though it may be made of its steel (which is much denser than water), because it encloses a volume of air (which is much less dense than water), and the resulting shape has an average density less than that of the water.

4.2.3 Lithospheric Flexure

The deflection of Earth's lithosphere in response to topographic loading and unloading is called the lithospheric flexure. Lithosphere subsides beneath the load, when a topographic load is generated by motion along a thrust fault. The width of this zone lies generally within the range of 100 to 300 kilometers varying from place to place. Rock uplift is driven when the lithosphere is rebound by a reduction in topographic load.

About 80% of the eroded rock mass is replaced by flexural-Isostatic uplift caused by erosion. This lengthens the time scale of mountain-belt denudation by a factor of approximately five. Because erosion must remove all of the rock that makes up the topographic load and the crustal root beneath it in order to erode the mountains down to the sea level. Flexural-isostasy plays a key role in nearly all examples of large-scale landform evolution and evaluation of ice sheets as well. The topographic load of the ice sheet causes lithospheric subsidence, thereby influencing rates of accumulation and ablation on the ice sheet.

4.2.4 The Concept of Equilibrium

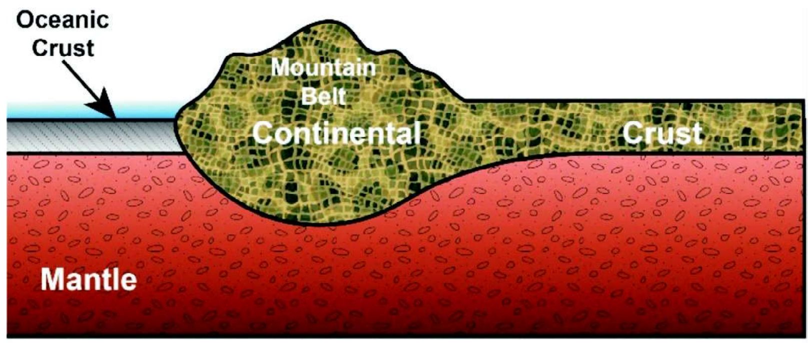
Isostatic equilibrium is an ideal state where the crust and the mantle would settle on account of the absence of disturbing forces. The waxing and waning of ice sheets erosion, sedimentation and volcanism are examples of processes that disturb isostasy. The physical properties of the lithosphere (the rocky shell that forms outer part of the Earth) are affected by the way the mantle and the crust responds to these disturbances.

Huge plates of crustal and upper mantle material (lithosphere) “float” on denser, plastically flowing rocks of the asthenosphere. The “depth” to which an object sinks depends on its weight and varies as the weight changes. This equilibrium or balance between blocks of crust and the underlying mantle is called **isostasy.** The taller a block of crust is (such as a mountainous region), the deeper it penetrates into the mantle because of its greater mass and weight. Isostasy occurs when each block settles into equilibrium with the underlying mantle. Blocks of crust that are separated by faults will “settle” at different elevations according to their relative mass.

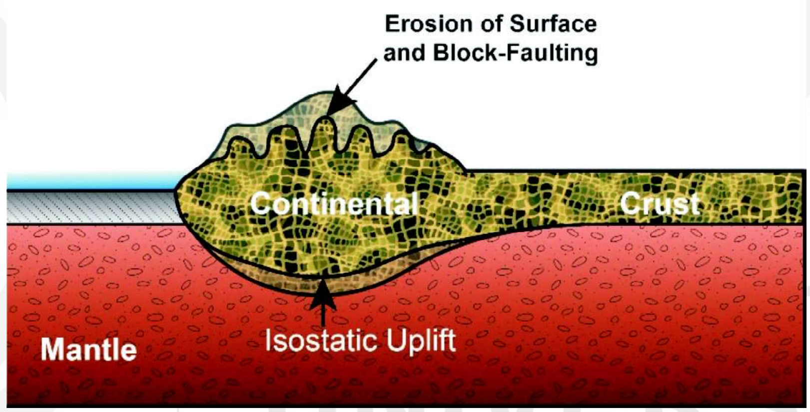
4.2.5 The Isostatic Adjustments

A model has been developed by a geomorphologist who explains the three stages involved in the formation of the most mountain ranges. The accumulation of sediments is the first stage. Rock deformation and crustal uplift caused by the tectonic collision is the second stage. The development of new mountain peaks due to upliftment of isostatic rebound is the final stage. Mountain building enters its final stage at the end of plate convergence. This stage is characterized by crustal uplift because of **isostatic rebound** and block-faulting**.** Isostatic rebound involves the vertical movement of continental crust that is floating in the plastic upper mantle. The weight of the crust in this region becomes less when the surface materials from mountains is removed by the erosion. With less weight, the continental crust makes an ‘isostatic adjustment’ causing it to rise vertically (float higher) in the mantle. This process also causes tensional forces to exist in a horizontal direction that breaks apart the continental crust into a number of blocks. Each block moves vertically to compensate for the tensional force which produces normal and graben faults.

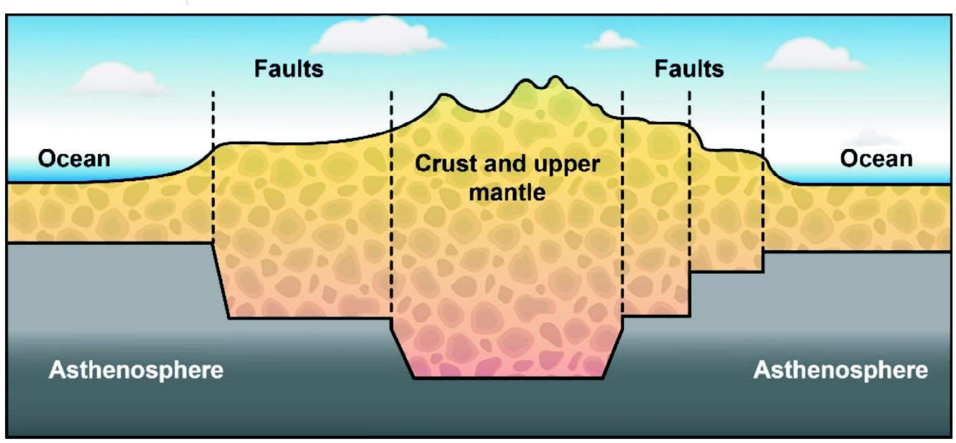
Many mountain belts stand high above the surrounding terrain because of the crustal thickening. These compressional mountains have buoyant crustal "roots" that extend deep into the supporting material below. If we put several blocks of wood of different thickness in water, you will notice that these blocks will float because wood is less dense than water, and the thicker block protrude higher above the surface of the water than the thinner block. At the same time, however, the thicker blocks also extend deeper into the water than the smaller blocks. They are more deeply submerged to compensate for their larger size. You could think of the submerged part of a block as the root of that floating block.



(a) Isostatic Uplift and Block-faulting stage.



(b) End of the Orogenic stage.



(c) Isostasy.

Fig. 4.2 : a) After the *orogenic stage*, weathering and erosion begins removing material from the surface of the newly created mountains; b) The removal of rock mass makes the area of the continental crust where the mountains are less heavy and end of the crust begins to float higher in the mantle; c) This isostatic rebound causes vertical uplift and the tensional forces due to the movement of the crust that creates normal and graben faults.

Visualize what would happen if another small block of wood were placed atop one of the blocks. The combined block would sink until a new isostatic (gravitational) balance was reached. However, the top of the combined block would actually be higher than before, and the bottom would be lower. This process of establishing a new level of gravitational equilibrium is called "isostatic adjustment". On the basis of the explanation given in the preceding paragraphs, you must have fully understood 'isostasy' and its principle. Now, you will move onto the other important aspects of isostasy and the development of the concept of isostasy as well.

SAQ 2

Spend 5 mins

a) What do you understand by buoyancy?

b) Write short note on lithoshperic flexure?

4.3 DEVELOPMENT OF THE CONCEPT OF ISOSTASY

4.3.1 Determination of Latitudes

The concept of isostasy grew out of the gradual thinking in terms of gravitational attraction of huge mountain masses. During the expedition to Andes in 1755, Pierry Bouguer found that the peak of ***Chimborazo*** was not attracting the plumb line as much as it should have. He then realized that the gravitational attraction of Andes was much smaller than that to be expected from the mass represented by these mountains. Sir Gorge Everest carried out a geodetic survey in the Indo-Gangetic plains for the determination of the latitudes. Similar discrepancy was noted during this survey. Thus, the debate on the discrepancies of the gravitational deflection of the plumb line and numerous explanations for these discrepancies resulted in the postulation of the concept of isostasy by different scientists.

Fig. 4.3 illustrates when British engineers noticed that the plumb bobs used for surveying did not hang vertically in northern India and that this effect increased as they approached the Himalayan mountains.

4.3.2 Isostasy as the Earth's Balance

Nature is a perfect system of balances. Matter and energy exist in finite (specific) amounts and cannot be created or destroyed. The Earth is a perfect example of nature's balance system. Rock particles are eroded from the mountain top, deposited in valleys or stream channels, compacted under their own weight into rock, and uplifted by mountain-building processes until they again rise to the top of the mountain. Deeper within the Earth, balancing processes also take place as major shifts in the upper part of the Earth's crust change the planet's gravitational balance. Under mountain ranges, the thin crust slumps or bows deeper into the upper mantle than where the land mass is thinner across continental plains. The land masses float on the crust and mantle-like icebergs float in seawater, with more of the mass of larger icebergs below the water than smaller ones. This balance of masses of the Earth's crust maintains the gravitational balance is called "isostasy."

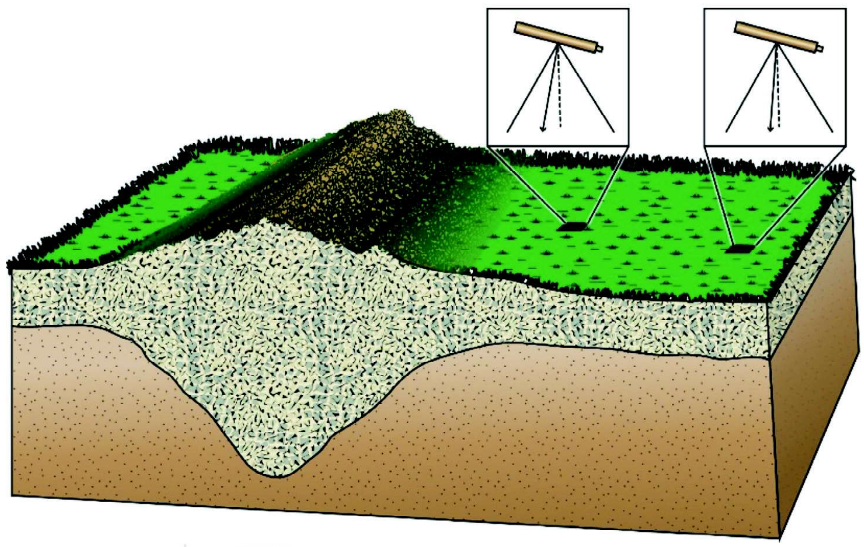


Fig. 4.3: Gravitational Deflection.

Remember that isostasy is not a process or a force. It is simply a natural adjustment or balance maintained by blocks of crust of different thicknesses that also maintains gravity. Isostasy uses energy to balance mass. The energy comes from the hydrological cycle, which is the path of a drop of water that originates in the ocean, evaporates to form a cloud, falls on the mountain as precipitation, and flows back to the sea carrying particles of rock and soil. The hydrological cycle derives its energy from gravity and solar radiation. As water flows or a glacier slowly grinds over land, energy is lost in that now-isolated system. Within Earth, energy comes from radioactive energy that causes convection currents in the core and mantle. Opposing convection currents pull the crust down into **geosynclines** (huge structural depressions). The sediments that have collected (by the processes of deposition that are part of the hydrological cycle) are squeezed in the downfolds and fused into magma. The magma rises to the surface through volcanic activity or intrusions of masses of magma as **batholiths** (massive rock bodies). When the convection currents die out, the crust uplifts and these thickened deposits rise and become subject to erosion again. The crust is moved from one part of the surface to another through a set of very slow processes, including those within Earth (like convection currents) and those on the surface (like plate tectonics and erosion).

In isostasy, there is a line of equality at which the mass of land above sea level is supported below sea level. So, within the crust, there is a depth where the total weight per unit area is the same all around the Earth. This imaginary, mathematical line is called the **"depth of establishing isostatic balance"**.

Isostasy describes vertical movement of land to maintain a balanced crust. It does not explain or include horizontal movements like the compression or folding of rock into mountain ranges. Greenland is an example of isostasy in action. The Greenland land mass is mostly below sea level because of the weight of the ice cap that covers the island. If the ice cap melted, the water would run off and raise the sea level. The land mass would also begin to rise, with its load removed, but it would rise more slowly than the sea level. Long after the ice melted, the land would eventually rise to a level where its surface is well above sea level. The isostatic balance would be reached again, but in a far different environment than the balance that exists with the ice cap weighing down the land.

4.3.3 Isostatic Effects

After learning about the development of the concept of Isostasy, we will now move onto the isostatic effects which are as follows:

Isostatic Effects of Deposition and Erosion

When large amounts of sediment are deposited on a particular region, the immense weight of the new sediment may cause the crust below to sink. Similarly, when large amounts of material are eroded away from a region, the land may rise to compensate. Therefore, as a mountain range is eroded down, the (reduced) range rebounds water. If a layer of ice is somehow sliced off the top of the iceberg, the remaining iceberg will rise. Similarly, the Earth's lithosphere "floats" in the asthenosphere, upwards (to a certain extent) to be eroded further. Some of the rock strata now visible at the ground surface may have spent much of their history at great depths below the surface buried under other strata. This rock stratum eventually lay exposed as those other strata which are eroded away and the lower layers rebound upwards again.

An analogy may be made with an iceberg - it always floats with a certain proportion of its mass below the surface of the water. If more ice is added to the top of the iceberg, the iceberg will sink lower in the water. If a layer of ice is somehow sliced off the top of the iceberg, the remaining iceberg will rise. Similarly, the Earth's lithosphere "floats" in the asthenosphere.

Plate Tectonics – Isostatic Effects of Plate Tectonics

When continents collide, the continental crust may thicken at their edges in the collision. If this happens, much of the thickened crust may move downwards rather than up as with the iceberg analogy. The idea of continental collisions building mountains "up" is therefore rather a simplification. Instead, the crust thickens and the upper part of the thickened crust may become a mountain range.

However, some continental collisions are far more complex than this, and the region may not be in isostatic equilibrium. So, this subject needs to be treated with caution.

Ice sheets – Isostatic Effects of Ice Sheets

The formation of ice sheets can cause the Earth's surface to sink. Conversely, isostatic post-glacial rebound is observed in areas once covered by ice sheets that have now melted, such as around the Baltic Sea and Hudson Bay. As the ice retreats, the load on the lithosphere and asthenosphere gets reduced and they *rebound* back towards their equilibrium levels. In this way, it is possible to find former sea cliffs and associated wave-cut platforms hundreds of metres above present-day sea level. The rebound movements are so slow that the uplift caused by the ending of the last glacial period is still continuing.

In addition to the vertical movement of the land and sea, isostatic adjustment of the Earth also involves horizontal movements. It can cause changes in the gravitational field and rotation rate of the Earth, polar wander, and Earthquakes.

Sea Level Changes

You might have heard about it. The sea level changes for a variety of reasons. These reasons can be put into two categories, eustatic and isostatic changes, depending on if they have a global effect on sea level or a local effect on the sea level.

a) ***Eustatic Change***

Eustatic change takes place when the sea level changes due to an alteration in the volume of water in the oceans. Alternatively, a change in the shape of an ocean basin and hence a change in the amount of water the sea can hold. Eustatic change **always** creates a global effect.

During and after an ice age, eustatic change takes place. At the beginning of an ice age, the temperature falls and water is frozen and stored in glaciers inland, suspending the hydrological cycle. This results in water being taken out of the sea but not being put back in leading to an overall fall in the sea level. Conversely, as an ice age ends, the temperature begins to rise and so the water stored in the glaciers will reenter the hydrological cycle and the sea will be replenished, increasing the sea levels. Increases in temperature outside of an ice age will also affect the sea level since an increasing temperature will cause the ice sheets to melt, putting more water in the sea.

The shape of the ocean basins can change due to tectonic movement. If the ocean basins become larger, the volume of the oceans becomes larger but the overall sea level will fall since there's the same amount of water in the ocean. Conversely, if the ocean basins get smaller, the volume of the oceans decreases and the sea level rises accordingly.

b) ***Isostatic Change***

Isostatic sea level change is the result of an increase or decrease in the height of the land. When the height of the land increases, the sea level falls and when the height of the land decreases the sea level rises. **Isostatic change is a local sea level change whereas eustatic change is a global sea level change**.

During an ice age, isostatic change is caused by the buildup of ice on the land. As water is stored on the land in glaciers, the weight of the land increases and the land sinks slightly, causing the sea level to rise slightly. This is referred to as ***compression***. When the ice melted at the end of an ice age, the land started to rise up again leading to fall in the sea level referred as ***decompression*** or isostatic rebound. Isostatic rebound is really a slow process continuing from the last ice age. You will be surprised to know that it is still taking place when you are reading this unit. Further, isostatic sea level change can also be caused by tectonic uplift or depression. As it normally occurs along the plate boundaries, such isostatic change is localized phenomenon in certain areas of the world.

c) ***Features of Sea Level Change***

Sea level change can produce many features along coastlines. Again, we can categorise these features based on how they're formed.

Emergent Landforms

Emergent landforms began to appear towards the end of an ice age. They occur when isostatic rebound takes place faster than a eustatic rise in the sea level. Put more simply, the land's height rises faster than the sea's. Emergent features are features of coastal erosion that appear to have developed well above the current sea level. Really, they developed when the sea *was* at that level and then the sea level changed during the ice age and now they're above the sea level.

One such emergent landform is a ***raised beach***. These are wave-cut platforms and beaches that lie above the current sea level. You can normally find some old cliffs (relic cliffs) too behind these raised beaches with wave-cut notches, arches, stacks etc. along them. These emergent features no longer experience coastal erosion. But they undergo various weathering processes including biological, chemical and physical etc.

Submergent Landforms

Submergent landforms are the opposite of emergent landforms. They form when the eustatic rise in sea level takes place faster than the isostatic rebound soon after an ice age. Basically, the water starts to flood the land and fills up landforms on the land. One submergent feature is known as ***Ria.*** This is a river valley that's been flooded by the eustatic rise in sea level. They're almost exactly like a typical river valley but they have even more water in them. The cross section of a ria is really similar to the one which you may find for a river in its lower course. One thing to note, the floodplain of the river also gets flooded, altering the cross profile of a ***ria*** ever so slightly so that it includes the floodplain.

Another submergent feature is a ***Fjord***. These are steeper and deeper variants of ***ria's*** that are relatively narrow for their size. They have a u-shaped cross profile and are often found in particularly icy sections of the world. In general, ***fjords*** are really deep. However, they have a shallow mouth (known as a *threshold*) as this is where the glacier deposits its load.

The final submergent feature is called ***dalmatian coastline***. These form in areas of the world where valleys (especially glacial valleys) lie parallel to each other. When the valleys are flooded by the rise in sea level, the tops of the valleys remain above the surface of the sea and appear to be a series of islands running parallel to the coastline. The best example of a dalmatian coastline is the one from which they get their name, the Dalmatian coast in Croatia. Many of you may be quite familiar with it, if not, then find out little more about it from the internet or books.

After going through the above paragraphs, you must have become fully aware of the effect of Isostasy on various relief features namely deposits, sea-level etc., and must be able to answer the following question.

SAQ 3

Spend 5 mins

Explain in short, how does the emergent landforms are formed?

4.4 VIEWS ON ISOSTASY

4.4.1 Airy's Theory

It is of utmost importance to know the views or theories of various geophysists to get clearer idea of what Isostasy is – some of them are as follows.

George B. Airy (1855), the Astronomer Royal, presented a paper arguing that the discrepancy could be explained if the mass excess of the mountains was underlain and supported by a mass deficit, similar to an iceberg floating in the ocean. There can be no other support than that arising from it. And, that the depth of its projection downwards being such that increased power of floatation thus gained is roughly equal to the increase of weight above from the topography. Downward projection of a portion of the Earth's light crust into the dense lava.

According to George Airy, the excess weight of the mountains is balanced by the lighter material below. The crust composed of lighter material is floating in the substratum of denser material i.e. ***Sial*** is floating over ***Sima*****.** The Himalayas are floating in the denser magma with their maximum portion sunk in the magma in the same way as the boat floats in water with its maximum part sunk in the water. If we assume the average density of the crust and the substratum to be 2.67 and 3.0 for every one part of the crust to remain above

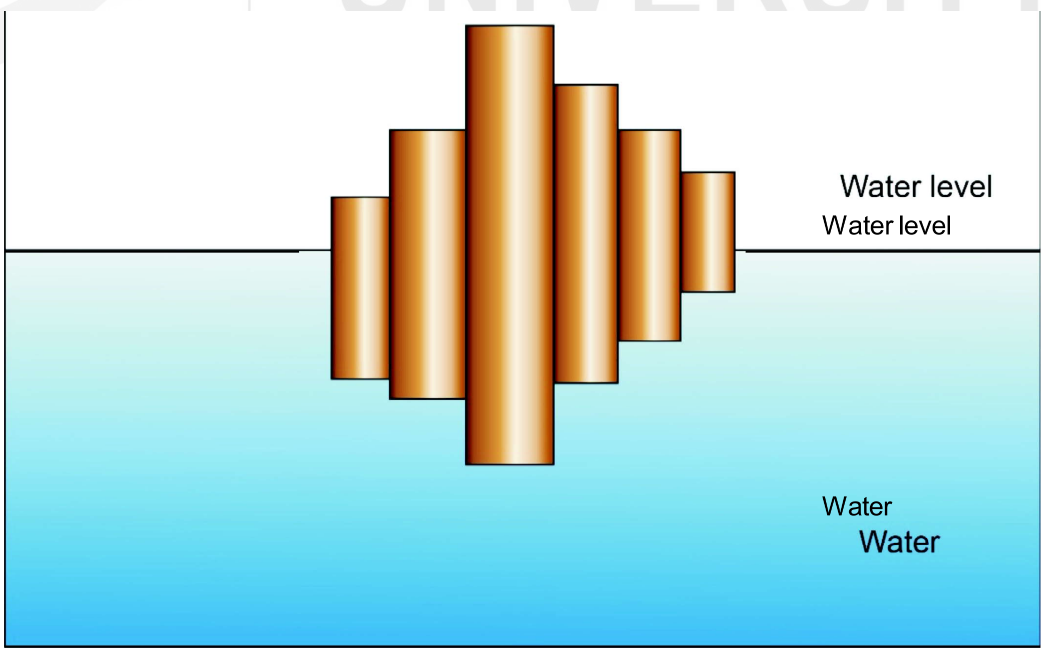


Fig. 4.4: Uniform density of different level features with varying thickness.

the substratum, then 9 part of the crust must be in the substratum. In another words, the law of floatation demands that 'the ratio free board to draught is 1:9.

The Himalayas according to airy were exerting their real attraction force because there exists a long root of lighter material in the substratum which balances the above. According to him, if the land column above the substratum is larger, its greater part would be submerged in the substratum, and if the land column is smaller, then small part would be submerged. According to him, density of different columns of land (mountains, plateaus and plains) remains the same. This means 'uniform density with varying thicknesses (Fig. 4.5).

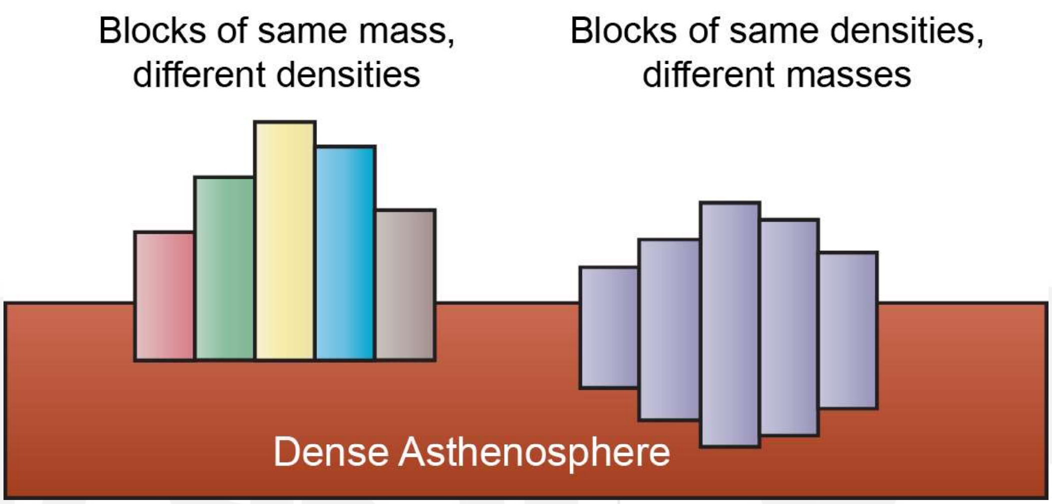


Fig. 4.5: Pratt Theory (left side) and Airy's Theory (right side).

Critical Analysis

According to Airy, every upstanding part must have a root below in accordance with its height in the ratio of 1:9. Then the Himalayas would have the root equal to the root 8848 X 9 = 79,632 meters deep. It would be wrong to assume that the Himalayas would have a downward projection of root of lighter material reaching such a great depth. Because, even if accepted such a long root would melt due to very high temperature prevailing there. The temperature increases with increasing depth at the rate of 1 degree centigrade per 32 meters. So at this depth, the temperature would be 2700 Degree Celsius, more than the temperature at the surface.

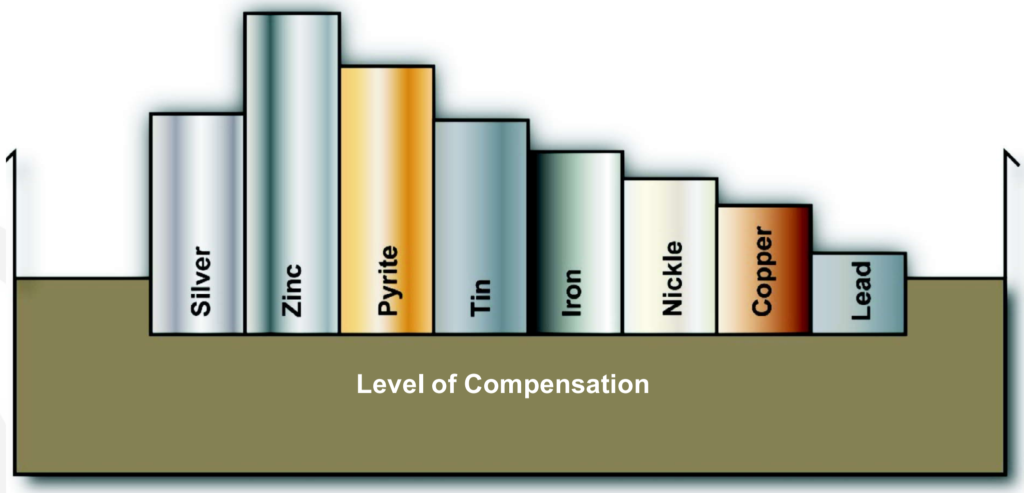
4.4.2 Pratt's Theory

H. Pratt (1855), a Cambridge-trained mathematician, then Archdeacon of Calcutta, used the mass excess of the Himalayas to account for the discrepancy. His only difficulty was that his quantitative analysis predicted a discrepancy of 15.885", three times larger than the observed figure of the same. His isostatic model features a horizontal crustal base. The crustal density varies from high under the seas to low under the high mountains. Thus, the pressure is everywhere equal at the base of the crust.

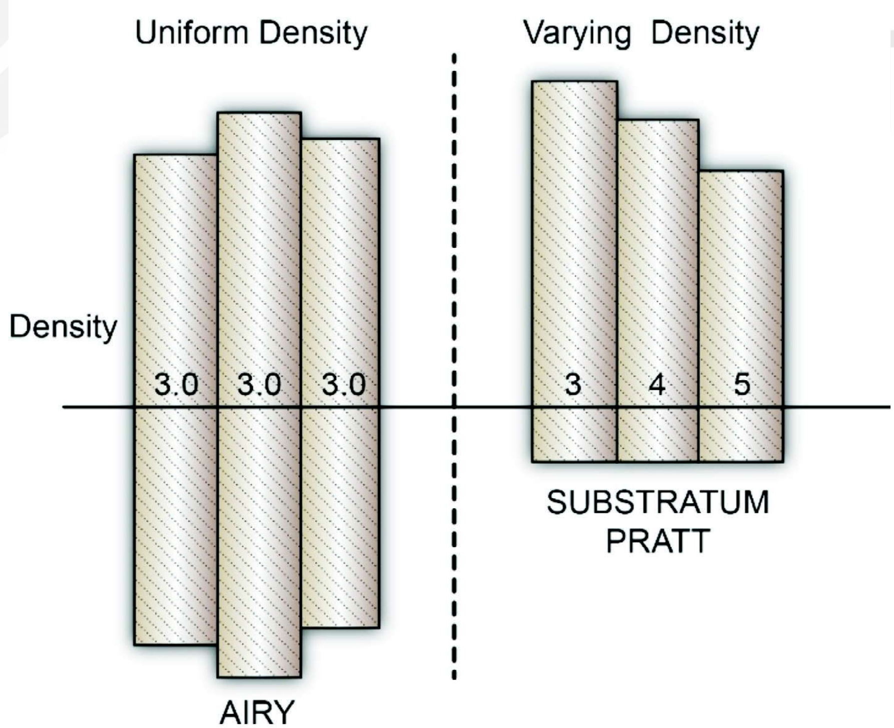
According to this theory, there is difference in the density of rocks in the crust at the heights of the crustal blocks. The density of the mountains is less than the plateaus, of plateaus less than the plains, and that of the plains is lesser than the ocean floor. This means that the density of elevated masses is lesser than the lower surface. Therefore, the blocks made-up of lighter materials are situated at higher elevation than those consisting of denser materials. In nutshell, you can assume that lighter material lies under mountains whereas heavier material under the oceans. A boundary between the upper blocks and the lower dense rocks lying at a uniform depth is known as the 'level of compensation'. It is here that the rocks constituting the elevated masses and depressed areas exert equal pressure.

Comparison of Airy and Pratt's view

Bowie has observed that the fundamental difference between Airy's and Pratt's view is that the former postulated a uniform density with varying thickness and the latter a uniform depth with varying density.



(a)



(b)

Fig. 4.6: a) Level of Compensation; b) Comparison between Airy and Pratt.

Today, the Airy model is thought to provide a good explanation for the elevation difference between the continents and the oceans. It presents fair picture of intra-continental elevations but a very poor one for ocean depths. Nowadays, the Airy-Woollard model, which allows variable densities in both the crust and mantle, does a better job within the continents.

4.4.3 Hayford and Bowie

The views of Hayford and Bowie are almost similar to that of Pratt. According to them, densities vary with elevation of columns of crustal parts. The density of the mountains is less than the ocean floor. In other words, the crust is composed of lighter material under the mountains than under the floor of the oceans.

There is such a zone below the plane of compensation where the density is uniform in lateral direction. Thus, according to them, there is inverse relationship between the height of columns of the crust and their respective densities (as assumed by Pratt) above the line of compensation. The plane (level) of compensation is supposedly located at a depth of about 100 kilometers. The column having the rocks of lesser density stands higher than the column having rocks of higher density.

Bowie performed an experiment in which he took eight pieces of different metals like iron, zinc, copper, lead, tin, silver, pyrite and nickel of equal thickness and varying height. He immersed these pieces into a vessel of mercury, and noticed that different columns of equal cross-section cut from various metals and ores having varying densities are seen floating in a basin of mercury but all of them reach the same line (level of compensation) and thus exert equal weight along the line of compensation.

Critical Analysis

1. The concepts of Hayford and Bowie states that the crustal parts (various reliefs) are in the form of vertical columns. It is not acceptable because the crustal features are found in the form of horizontal layers.

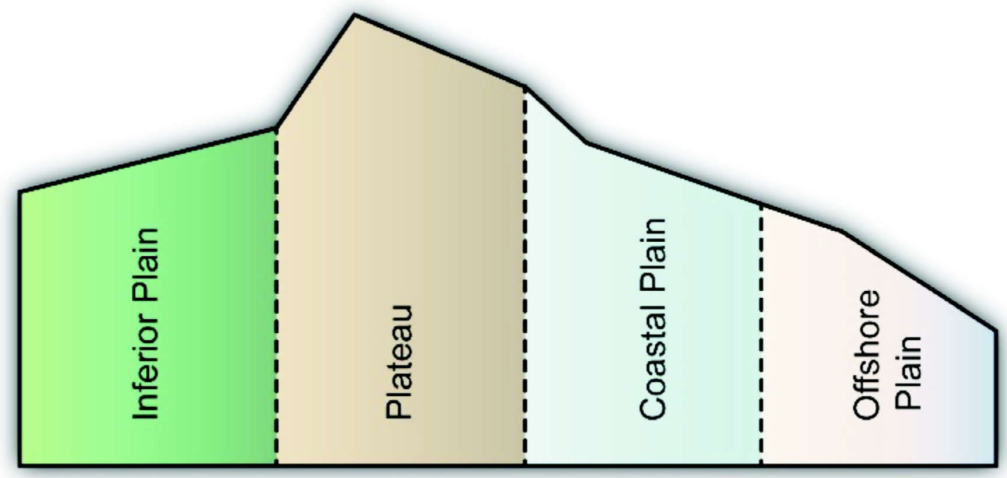
2. He assumed that the plane of compensation is located at a depth of about 100 kilometers. It is not possible for the rocks to remain in the solid state at such high temperature which exists at this depth.

4.4.4 Joly

Joly disapproved the views propounded by Hayford and Bowie about the existence of the level of compensation at the depth of about 100 kilometers. According to him, there exists a layer of 10 miles (16 kilometers) thickness below a shell of uniform density. The density varies in this zone of 10 miles thickness. Joly thus assumed the level of compensation not as a linear phenomenon but a zonal phenomenon as he did not believe in ‘line of compensation’ rather he believed in a zone of compensation. In this layer (zone of compensation), the lower parts of columns of different densities are not equal. He was of the view that the continent i.e. ***Sial*** and its different columns are floating in this layer, thus maintaining **‘hydrostatic equilibrium’**.

In this way, Joly explained his views on the basis of law of floatation (it may be remembered that Joly did not mentioned this). That's why we only infer the ideas of floatation from Joly's concepts.

He showed that when an object floats in the water, it displaces water equal of its own weight. In this way, Joly's views are similar to Airy. This view of Joly is in close agreement with floatation idea. The areas of low densities in the 10 miles layer correspond with downward projections of the light continental crust, while those of higher density represent the intervening areas filled with material of the heavier under stratum (Fig. 4.7).



Level of Compensation

Fig. 4.7: Level of Compensation according to Hayford.

4.4.5 Heiskanen

In his hypothesis, Heiskanen combined the concepts of both airy (uniform density with varying thickness) and Pratt (varying densities in different columns). According to him, density of rocks varies within the columns as well as between the columns. His theory of isostasy is also confirmed by the seismic data. It has been observed that the average density of rocks at sea-level is more than those at higher elevations. And, this variation of density is thought to continue further downwards causing the deeper rocks more dense than the shallower ones. Thus, different blocks are thought to have different densities and accordingly extend downward to different depths. It explains for the roots of mountains and for the variations in density in different parts of the crust. The density of rocks of different sections (columns) of the Earth's crust also varies. Thus, it appears that the density of rocks varies both vertically as well as horizontally.

Critical Analysis

1. The theory of isostasy convincingly explains the vertical uplift of the mountains but it has not yet been possible to establish that isostasy is the factor initiating tectonic movements.

2. The role of isostasy in the development of the Earth's crust is rather modest and not decisive.

3. The idea of isostasy is supported by the fact that the melting of ice from the glaciers in Scandinavia led to a reduction of load and the consequent rise of the area.

4.4.6 Holmes

Holmes, on the basis of evidence from the seismic waves assumed the Earth to be composed of many layers. He concluded that the elevated parts were formed of the rocks with less density. That is why the layer of ***Sial*** under the mountains is 40 kilometers or above whereas under the plains, it is only 10 to 12 kilometers. Whereas below the ocean floor, the ***Sial*** layer is either very thin or is absent. He is clearly of the opinion that upstanding crustal parts are made of lighter material. In order to balance them, the major portion of these higher columns are submerged in greater depth of lighter materials of very low and high density material is found under the low lying parts (Fig. 4.8).

Fig. 4.8: Joly's Concept of Isostasy.

4.4.7 Vening-Meinesz or Flexural Isostasy

F. A. Vening-Meinesz was a Dutch geophysicist, active during the middle years of the twentieth century. He is famous for his early studies on gravity anomalies at sea, especially over deep-sea trenches. These measurements were made with special pendulums in a submerged and stationary submarine. You will wonder that he along with other scientists soon realized that the key to their puzzle lay in the rheological behavior of rocks. It states that when rocks are cold, rocks are strong and can sustain loads for millions or billions of years without deforming. Near the melting point, however, rocks are weak and deform readily over geologic time scales. "Hot" and "Cold" refers to closeness to melting temperatures on the Kelvin (absolute) temperature scale.

Applied to the Earth, these observations indicate that there is a "cold", strong outer rheological layer. This may or may not coincide with the crust or lithosphere or any other named layer. Similarly there is a "hot", weak,

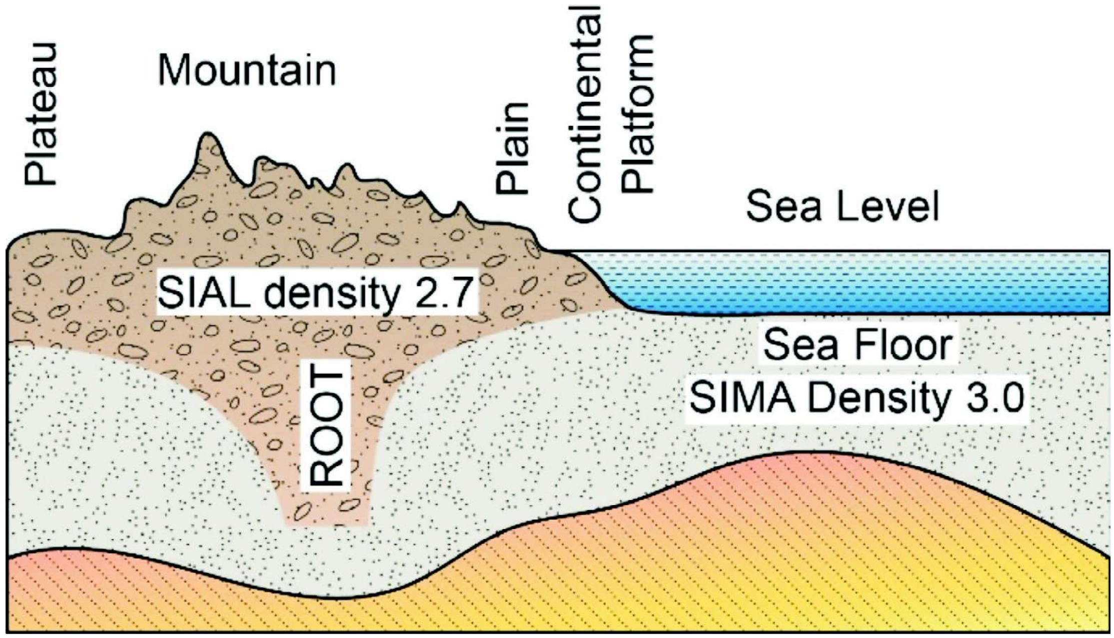


Fig. 4.9: Holmes Hypothesis of Isostasy.

underlying layer that can flow rapidly over intervals as short as a few thousand years (post-glacial rebound shows this). This deformable layer is solid with respect to short-term loading (Earthquake waves) but flows for loads of long duration. Even deeper lies stronger rock. It's very hot but not so close to melting temperatures as melting is inhibited by high pressures.

In the Vening-Meinesz or flexural model, surface loads such as ice-sheets are largely supported by bending of a cold, outer and elastic layer with a thickness in the range of about 10 to 100 kilometers. We can model this kind of support by using engineering formulae for bent beams. At the Earth's surface, the rocks are strong and can sustain steep slopes. At depth the rocks are weak, but still solid, and flow in response to differential loading. In this model, the mass of unit columns down to the depth of flow is not necessarily constant. It can vary from place to place. Using our engineering formulae, we can estimate the elastic thickness. Where it is thin, the vertical displacements are large for a given load and are concentrated in a narrow region under and around the load. Where the thickness of the elastic layer is large, the vertical displacements are smaller but occur to great distances from the load.

In the ocean, such studies show that the elastic thickness increases as the plate ages. The base of the elastic plate seems to follow roughly the 450°C isotherm, not the base of the lithosphere plate (about 1300°C). On the continents, the picture is less clear because of often complex rheological layering (for example, weak quartz-rich plutonic rock). Clearly, given the dominant control be temperature, the elastic thickness can change with time. This situation may lead us to many questions. How can we harmonize this local isostasy with the regional isostasy based on a thickening lithosphere?

Studies of flexural isostasy have been made around ice sheets, ice caps, deltas, deep-sea fans, volcanic islands, foreland basins and even subduction zones. The loading may be external, such as an ice cap, or internal such as a mafic pluton intruded into the lighter rock.

4.4.8 Isostasy v/s No Isostasy

Two observations to isostasy in general are as under:

1. At the same time, when models of isostasy were being developed, other scientists were learning to probe the deep interior of the Earth. Two strong arguments for a solid Earth were advanced. If the Earth were "solid", in our everyday use of the term, rock could not flow and isostatic equilibrium would not occur.

2. The older argument for a mainly solid Earth was based on analysis of ocean tides. Were the Earth fluid, like the sea, it would respond to tidal forces as does the ocean water and only small tides would be seen. The Earth and ocean water would move together and there would be little relative motion (that is, no observable tide). At about the beginning of the twentieth century, seismologists tracked shear waves throughout all the Earth down to a small liquid core (the solid inner core was discovered much later). These studies provided convincing evidence for a mainly solid Earth because shear waves will not propagate through liquids.

   If the Earth is solid, how can rocks flow to gain isostatic balance?

   Another observation to Airy and Pratt's Isostasy: In both these models, isostasy is local. That is, any adjacent rock columns can move up and down independently in response to changing loads. You'll recall lab exercises with floating wooden blocks. The problem, of course, is that this freedom of motion implies that rock has no shear strength. On the other hand, the mere existence of steep topographic slopes demonstrates that rocks do have long-term shear strength; whereas mountains don't seem to ooze away and flatten out (or are there really post- orogenic collapse involving detachment faults?). How can we reconcile these contradictions?

4.5 SUMMARY

In this unit, thus, you have learnt following concepts, theories and issues as stated below:

- You have learnt that Earth is a moving planet. It rotates on its axis as well as revolves around the Sun. Different relief features of varying magnitudes are found on its surface. On one side, we have highest peak like ***Mount Everest*** and on the other we have ***Mindanao*** trench which surprises us and forces us to think how these relief features remained balanced on this moving Earth.
- You have learnt that in order to satisfy this curiosity, the geodetic survey was conducted in the Indo-Gangetic plains and some other areas, and gravitational anomalies were noticed during this process.
- You have learnt that low density rocks are found beneath the different relief features in proportion to their depth which exerts the same weight on the level of compensation.

- You have also learnt that Dutton was the first person to term this process as 'Isostasy'. Later on, many scientists gave their views on it. It was also proven that the process of isostasy is a continuous process.

4.6 TERMINAL QUESTIONS

1. What factors determine the density variations with depth on the Earth?

2 Compare the views of Airy and Pratt on isostasy.

3. Give critical analysis on the views of Hayford and Bowie.

4. Which scientist believed that the level of compensation is not a linear but a zonal phenomenon and why?

5. What is the effect of isostasy on ice sheets?

4.7 ANSWERS

Self-Assessment Questions

1. Isostasy simply means a mechanical stability between the upstanding parts and low lying basins on a rotating Earth.

2. a) **Buoyancy** refers to an upward force exerted by a fluid which opposes the weight of an object immersed in it.

   b) The deflection of Earth's lithosphere in response to topographic loading and unloading is called the 'Lithospheric Flexure'. Lithosphere subsides beneath the load, when a topographic load is generated by motion along a thrust fault. The width of this zone lies generally within the range of 100 to 300 kilometers varying from place to place. Rock uplift is driven when the lithosphere is rebound by a reduction in topographic load.

3. Emergent landforms begin to form towards the end of an ice age and they occur when isostatic rebound takes place faster than a eustatic rise in the sea level. That means the land's height rises faster than the sea's. Emergent landforms are features of coastal erosion that appear to have developed well above the current sea level. Actually, they developed when the sea *was* at that level and then the sea level changed during and ice age, now they're above sea level.

Terminal Questions

1. You should be able to clearly mention the prime factors that determine the density variations with depth on the Earth by referring to Sub-sec. 4.2.2.

2. Bring out the essence of differing views on isostasy by referring to Sub-sections 4.4.1 and 4.4.2.

3. Your answer should cover the major points of critical views as proposed by two scholars. You can refer to Sub-sec 4.4.3.

4. You answer should clearly mention the pertinent reasons as to why level of compensation is not a linear but a zonal phenomenon as proposed by the scientist. You can refer to Sub-sec. 4.4.4.

5. Aptly highlight the key effects of isostasy on ice sheets by referring to Sub-sec. 4.3.3.

4.8 REFRENCES/FURTHER READING

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GLOSSARY

Abiotic components	:	It denotes the physical environment encompassing air, water, soil, land and energy resources in the ecosystem.
Aphelion	:	It refers to the point in Earth's elliptical orbit when the position of planet Earth is farthest from the Sun.
Asteroid	:	It refers to the belt of myriad minute heavenly bodies known as 'Planetoids' which revolves in the Solar System between 'Mars and Jupiter'.
Axial plane	:	It bisects the either upper or lower angle which lies between the limbs of a fold on each side of the crest-line corresponding to an anticline or the trough-line of a syncline.
Buoyancy force	:	It refers to an upward force exerted by the fluid on the objects submerged in the fluid mediums.
Biotic components	:	It is also called organic components that include plants, animals and micro-organisms etc.
Biome	:	It means the total assemblage of flora and fauna that can survive in a given geographical area.
Comet	:	It is a small body which usually rotates around the Sun in an elongated orbit.
Core	:	This is the centre of the Earth mainly composed of metallic iron and nickel.
Core-mantle boundary	:	The liquid outer core and solid lower mantle is marked by a boundary known as 'Gutenberg Discontinuity'.
Crust	:	It is the outermost and thinnest layer of the Earth's interior mostly comprising rocky materials.
Earthquake	:	It is an abrupt movement or shaking of the Earth's crust. Earthquake is generated by the seismic waves with varying velocity. It originates along the fault planes beneath the Earth's surface.
Ecosystem	:	It refers to the community of plants and animals within a particular physical environment. These are linked by a flow of materials through the biotic as well as abiotic components of the ecosystem.
Environmental Impact Assessment	:	It refers to a technique that enables the assessment of the positive and negative impacts of developmental projects on environment before execution.
Isostasy	:	The continental crust of the Earth is characterized by visible part lying above the Earth's surface and a lower invisible part that lies beneath the Earth's surface. The balance between these two is known as 'isostasy'.

Lava	:	It refers to the magma that reaches the Earth's surface during the volcanic eruption.
Mantle	:	It is the middlemost layer. Mantle lies between the crust and core layers of the Earth's interior.
Meteorite	:	It indicates towards any part of a meteoroid which survives through Earth's atmosphere and then strikes the Earth's surface in its traverse.
Mohorovicic discontinuity (Moho)	:	It denotes the boundary lying between the crust and mantle characterised by the rapid rise in seismic activities.
Perihelion	:	It signifies the point when Earth comes nearest to the Sun in its orbit.
Photosynthesis	:	It refers to the basic process in which plants produce stored chemical energy from water and carbon dioxide. This entire process comes into function from the sunlight energy.
Rock cycle	:	It is a term which signifies the long-term constant recycling of mineral material from one type to another type.
Seismology	:	It studies the occurrence of Earthquakes along with mechanical properties of the Earth's interior.
Seismogram	:	It records the passage of seismic waves on a seismograph. The position and force of an Earthquake may be learnt through this record.
Seismic wave	:	A wave produced either by the shaking of the ground beneath the Earth's surface known as Earthquake or it can also be generated artificially in a stimulated environment.
Solar System	:	It consists of the nine planets and the asteroids that revolve in near circular orbits around the Sun in almost the same plane.
Supernova	:	It is a kind of exploding star which magnifies its luminosity by thousand times.
Wavelength	:	It refers to the horizontal distance that separates two successive crests or troughs.

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