NETAJI SUBHAS OPEN UNIVERSITY

মানুষের জ্ঞান ও ভাবকে বইয়ের মধ্যে সঞ্চিত করিবার যে একটা প্রচুর সুবিধা আছে, সে কথা কেহই অস্বীকার করিতে পারে না। কিন্তু সেই সুবিধার দ্বারা মনের স্বাভাবিক শক্তিকে একেবারে আচ্ছন্ন করিয়া ফেলিলে বুদ্ধিকে বাবু করিয়া তোলা হয়।

—রবীন্দ্রনাথ ঠাকুর

ভারতের একটা mission আছে, একটা গৌরবময় ভবিষ্যৎ আছে, সেই ভবিষ্যৎ ভারতের উত্তরাধিকারী আমরাই। নূতন ভারতের মুক্তির ইতিহাস আমরাই রচনা করছি এবং করব। এই বিশ্বাস আছে বলেই আমরা সব দুঃখ কষ্ট সহ্য করতে পারি, অন্ধকারময় বর্তমানকে অগ্রাহ্য করতে পারি, বাস্তবের নিষ্ঠুর সত্যগুলি আদর্শের কঠিন আঘাতে ধূলিস্যাৎ করতে পারি।

—সুভাষচন্দ্র বসু

Any system of education which ignores Indian conditions, requirements, history and sociology is too unscientific to commend itself to any rational support.

—Subhas Chandra Bose

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NSOU • SLM • PGES • CC • 202

NETAJI SUBHAS OPEN UNIVERSITY

Post Graduate Degree Programme

PGES

PGES CC 202

SELF LEARNING MATERIAL

ENVIRONMENTAL GEOSCIENCES AND CLIMATE CHANGE

PREFACE

In the curricular structure introduced by this University for students of Post-Graduate degree programme, the opportunity to pursue Post-Graduate course in a subject is introduced by this University is equally available to all learners. Instead of being guided by any presumption about ability level, it would perhaps stand to reason if receptivity of a learner is judged in the course of the learning process. That would be entirely in keeping with the objectives of open education which does not believe in artificial differentiation. I am happy to note that the university has been recently accredited by National Assessment and Accreditation Council of India (NAAC) with grade 'A'.

Keeping this in view, the study materials of the Post-Graduate level in different subjects are being prepared on the basis of a well laid-out syllabus. The course structure combines the best elements in the approved syllabi of Central and State Universities in respective subjects. It has been so designed as to be upgradable with the addition of new information as well as results of fresh thinking and analysis.

The accepted methodology of distance education has been followed in the preparation of these study materials. Co-operation in every form of experienced scholars is indispensable for a work of this kind. We, therefore, owe an enormous debt of gratitude to everyone whose tireless efforts went into the writing, editing, and devising of a proper layout of the materials. Practically speaking, their role amounts to an involvement in 'invisible teaching'. For, whoever makes use of these study materials would virtually derive the benefit of learning under their collective care without each being seen by the other.

The more a learner would seriously pursue these study materials, the easier it will be for him or her to reach out to larger horizons of a subject. Care has also been taken to make the language lucid and presentation attractive so that they may be rated as quality self-learning materials. If anything remains still obscure or difficult to follow, arrangements are there to come to terms with them through the counselling sessions regularly available at the network of study centres set up by the University.

Needless to add, a great deal of these efforts is still experimental—in fact, pioneering in certain areas. Naturally, there is every possibility of some lapse or deficiency here and there. However, these do admit of rectification and further improvement in due course. On the whole, therefore, these study materials are expected to evoke wider appreciation the more they receive serious attention of all concerned.

Professor Indrajit Lahiri
Authorised Vice-Chancellor
Netaji Subhas Open University (NSOU)

Netaji Subhas open University

Post Graduate Degree Programme
Choice Based Credit System (CBCS)
Subject : P.G. Environmental Science (PGES)
Course : Environmental Geoscience and Climate Change
Course Code : PGES-CC-202

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Netaji Subhas Open University

P.G. Environmental Science
PGES-CC-202

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Unit - 1 ❑ Fundamental of Earth Processes

Structure

1.1 Objectives

By successfully completing this unit, you will be able to :

- know the theories behind the origin of the earth
- visualize the geological time scale
- demonstrate the structure of the earth
- learn how the mountains are build
- understand different structure developed by water
- understand different landform development due to wind action
- understand different landform development due to glacier movements

1.2 Introduction

Earth processes shape the earth's surface and the sedimentary deposits that record those processes link human timescales to geologic history. The dynamic environments at earth's surface reflect connections between biological, physical and chemical systems. The study of earth processes is based on number of fundamental principles, some of which are unique. The earths topographic features are mixtures of landforms being formed at the present time and others that have been shaped in the past by processes no longer active, it embraces the investigation of both mechanics of modern processes and the historic influence of geologic time.

The surface processes responsible for most of the earth's topographic features are :

- Weathering
- Mass wasting

- Running water
- Ground water
- Glaciers
- Waves
- Wind
- Tectonism
- Volcanism

Earth's surface is a dynamic interface across which the atmosphere, water, biota, and tectonics Interact to transform rock into landscapes with distinctive features crucial to the function and existence water resources natural hazards, climate, biochemical cycles, and life.

1.3 Origin of Earth

In the ancient times, the earth occupied a central place in the universe. Even Aristotle, the famous Greek Philosopher proclaimed that the earth was the centre of the universe. Ptolemy declared that the sun, the moon and the stars revolved round the earth. Pythagoras and Philolaus stated that the Earth was not stationary in the universe but rotates around its axis and makes one rotation in 24 hours. The famous thinker Aristarchus is reported to have believed that the Earth revolves around the sun. Galileo & Copernicus had to keep their mouths shut inspite of their intense desire to say the truth. It was an important turning point in the history of thought when on January 17, 1610 Galileo, a prominent mathematician of Padua University invented a telescope and proved in a practical way that the Earth like any other plane was an ordinary one and revolved around the sun.

1.3.1 Solar System :

We know that the earth is a member of the solar system. Sun, the principal member of the system is located in the centre and revolving round the sun are the nine planets of which our earth is one. 98.7 % of the matter of the solar system is concentrated in the sun. From the point of view of mass, its weight is 2 × 10 (27) tonnes and is 3,30,000 times that of the earth. Its diameter is 109 times that of the earth. Basic information of the planets is given below –

Table 1.1 : Basic information of the planets

Planets	Distance from the Sun in Million km	Average Density (gm/cc)	Period of Revolution Around the Sun	Period of Rotation	No. of Sub-planets
Mercury	58.0	5.10	88 Days	58.64 Days	00
Venus	108.0	5.30	225 Days	243 Days	00
Earth	149.6	5.52	365.256 Days	23 Hours 56 Min.	01
Mars	227.9	3.94	687 Days	24 Hrs. 37 Min.	02
Jupiter	777.9	1.34	12 Years	9 Hrs. 50 Min.	16
Saturn	1427	0.70	29.46 Days	10 Hrs. 14 Min.	23
Uranus	2867	1.55	84.01 Days	17 Hrs. 5 Min.	12
Neptune	4504	2.27	164.8 Days	16 Hrs. 6 Min.	2
Luto	5936	1.50	247.69 Days	6.38 Days	1

These planets can be divided into two groups – Terrestrial or the Inner Planets or Pygmy Planets and the Outer Planets or Jovian Planet or Giant Planet.

Subject	Terrestrial Planet	Jovian Planet
Avg. Relative Density	5	1.5
Size	Small as compared to Jovian	Larger as compared to terrestrial planets
Composition	Rocks, solid material with minor amount of gases	All gaseous, mostly hydrogen, helium with varying amounts of ice like etc.

1.3.2 Origin of the Earth

Man has been curious about the origin of the earth and the solar system from ancient times and various hypothesis have been put forward time to time on the basis of imagination, speculation as well as observation. None of these, however, can be considered to be wholly satisfactory acceptable. There appears to be, however, unanimity on one point regarding the origin of the solar system and that is that all the planets of the solar system appear to have originated broadly at the same time and in a similar way, as the direction of both their rotation and revolution round the sun are the same. But there are several other questions for which no satisfactory answers are available.

Based on the scientific studies and evidences, some conclusions have been arrived at in respect of the origin of the earth and the solar system about which there is not much difference of opinion. For instance, it is now generally believed that the stars of our and other galaxies came into existence about 7,000 million years ago and possibly the earth came into existence about 4500 to 5000 million years ago. We may divide the scientific views regarding the origin of the earth broadly into two classes :

(A) Monistic Hypothesis : This hypothesis believed that, solar system and earth originated from a single star or nebula. The chief protagonists of this school of thought are Kant, Laplace, Hoyle, Kuiper *etc.*

(B) Dualistic Hypothesis : Solar system and earth have originated as a result of the coming together of two stars. In this school of thought we may include the Planetesimal hypothesis of Chamberlin & Multon, tidal hypothesis of Jeffreys *etc.*

1.3.2.1 Monistic Hypothesis/ Parental Hypothesis

1.3.2.1.1 The Gaseous Hypothesis of Kant

Immanuel Kant, the Prussian philosopher, presented his gaseous hypothesis in these treaties entitled “The General Natural History and Theory of the Heavens or the Essay on the Working and Mechanical Origin of the Entire Universe on the Basis of Newtonian Laws” in 17. Obviously, Kant hypothesis was primarily based on Newton’s law of gravitation and rotatory motion. Ge assumed that, primordial matter was scatter in the universe. This matter consisted of small, hard and cold particles. These particles were attracted towards one another under the influence of gravitational pull. In due course of time, they began to collide against one another. The friction between these particles generated heat and the temperature of the primordial matter started rising. The collision also generated random motion in the primordial matter and angular velocity was produced. Thus, original cold and motionless cloud of primordial matter became a vast hot nebula. It was so vast that it extended from the sun in the centre to as far away as the orbit of the outer most planet. The rise in temperature changed the state of primordial matter from solid to gaseous. The repeated collision of the particles increased random motion and angular velocity to such an extent that the nebula started rotating at a terrific speed and large amount of centrifugal force was generated. When centrifugal force became larger than the gravitational force, a ring was thrown away from the equator of the nebula. This process was repeated nine times and nine rings were formed. The irregularity of the rings caused the development of cores which led to the formation of corresponding planets. Our earth is a planet formed one of the nine rings which got separated from the nebula. By small scale repetition of the same process, the gaseous mass of some of the planets throw away rings which became their satellite. The remaining part of the original gaseous mass is our present sun. Thus, the entire solar system comprising the sun, nine planets and their satellites came into being.

Merits :

- It was the first theory which is based on fundamental scientific facts such as Newton's law of gravitation and motion.
- Kant's hypothesis appears to be simple and sounds more logical.
- This theory provided ground for developing future ideas about the origin of earth.

Demerits :

- The basic assumption on which Kant based his hypothesis was that there was primordial matter in the universe. He has not explained the source of origin of the primordial matter.
- According to Kant's view, the collision between the particles of the primordial matter was due to gravitational pull. Scientists have asked whether this force did not exist before the collision and if it existed, what prevented it to act and collision take place.

- Kant did not explain how angular momentum was generated in the primordial matter after collision of its particles.

1.3.2.1.2 The Nebular Hypothesis of Laplace

Laplace was a French scientist. He explained the origin of the earth and the solar system in the last year of the eighteenth century.

He started that primordial matter in the beginning existed in the form of intensely hot and rotation gaseous mass called Nebula. As the gaseous mass cooled, its volume decreased. Due to decreasing volume, its rotation increased. The mass of the nebula began to shift around the Equator. Due to the increased rotation, centrifugal forces also increased. The matter of the nebula was attracted to the centre of the nebula on account of the force of gravitation. Thus, the two forces (centrifugal and gravitational) were opposed to each other. When the centrifugal force became equal to the force of gravitation, the excess matter around the equator separated from the equator in the shape of a ring and became weightless. With time, as the nebula cooled further, its rotation increased which increased its centrifugal force. When the centrifugal force exceeded the gravitational force, the ring moved away from the nebula and broke into many smaller rings. These rings, on cooling, took the forms of planets and sub-planets. The central part of the nebula which remained the sun.

Merits :

- It explains the rotation and the revolution of the planets and sub-planets because it assumes a hot and rotating nebula.
- The ring separating from the rotating nebula must be rotating and could took the form of a planet.
- All the planets of the sun revolve around the sun in almost the same plane. Laplace explained that the planets formed from one ring, must of necessity, revolve in one plane.

Demerits :

- Laplace paid little attention to the quantitative aspect of the hypothesis. The present mass, the distance and the speed of the members of the solar system are such that it can be proved that the angular momentum of the nebula was so low that a ring could not separate out of the nebula.

- Laplace did not explain how the parts of the ring took the form of solid masses. In fact, the ring should disappear by disintegration into tiny particles.
- Some of the sub-planets of the Uranus and Saturn revolved in direction to those of other planets. This fact cannot be explained on the basis of the hypothesis.

1.3.2.1.3 The Nova Hypothesis of Hoyle & Lyttleton

F. Holey and Lyttleton have jointly formulated this hypothesis, this is based on bright star called nova as its name indicate. There are several stars in the universe which suddenly increase their brightness by 100 times. The brightness of such star may be several thousand times that of the sun. Such bright stars are called nova. Some of the stars are reported to have brightness one billion times that of our sun, although for a short period Stars with such a high degree of brightness are called supernova.

It has been found that the planets of our solar system are made of heavy elements like oxygen, silica, aluminium, iron, calcium *etc.* These elements account for 98 percent of the planets. Like elements like hydrogen and helium comprise only one percent of the planets. In sharp contrast the stars are formed of lighter mineral like hydrogen and helium. Thus, a major question arises that how planets of heavy material could be formed from stars of light material. To solve this riddle, Hoyle conceived the nova hypothesis.

According to this hypothesis, there were two stars *i.e.*, binary stars. One of them was our sun and the other was a much bigger and powerful companion star which became supernova at a later stage. It has been scientifically observed that the energy which is emitted by a star in the form of heat, light, *etc.* is generated by nuclear fusion. The star generally contains large quantities of hydrogen, the nuclei of which combine with each other to form heavier matter *i.e.*, helium. Consequently, vast amount of energy is released by the stars. A star whose helium is consumed in the process of nuclear reaction and release of energy is called supernova.

According to Hoyle 15 to 20 nova are seen every year but a supernova is seen only once in two or three centuries. Because of high temperature, the lighter hydrogen in the star is continuously change into heavier helium; thus, producing tremendous amount of energy. Both the companion star produced far greater amount of energy than the sun. When large amount of energy was emitted by the companion star, *i.e.*, nova, it contracted at a very fast rate which suddenly increased its rotational speed. In due course of time of the contraction and rotational speed of the nova increased tremendously and its hydrogen was almost completely consumed. Thus, it came close to a split and then violently exploded. Due to this violent explosion in the companion star (now supernova), huge mass of dust came out of it. Hoyle believed that the mass of dust thus coming out of the supernova was ejected unevenly, *i.e.*, more towards the sun and less on the opposite side. This matter was attracted by the sun due to its gravitational pull. Consequently, it started revolving around the sun and in due course of time condensed into planet.

However, Lyttleton expressed a slightly different view. He believed that after the explosion, the matter of the supernova was thrown equally in all the directions. Under such circumstances, the recoil of the gigantic stellar explosion might drive the nucleus of the companion out of the gravitational reach of the sun, while leaving a residual mass of gas capable of forming a rotating circular disc around the sun from which planetary condensation might form. In this way, the hot and gaseous matter of the disc provided material for the future planets. With the passage of time, part of the matter of the disc was converted into planets. It is worth mentioning here that the intense heat generated at the time of explosion of the supernova resulted in the formation of heavy elements like helium, carbon, oxygen, silicon *etc.* Thus, it is clear that the planets were not made from the light material of the sun but from the heavy material thrown out of the supernova due to nuclear reaction and violent explosion. Lyttleton further pleaded that some of the planets grew much bigger in size by attracting more material from the disc and their rotation also increased. With the passage of time, those bigger planets divided themselves into two parts. A chain of smaller bodies was created between the two parts due to their gravitational pull. The smaller parts were near the planets and became their satellites. The middle part of the chain was occupied by larger body which became independent planets. Lyttleton believed that Jupiter and Saturn of the present solar system are two broken parts of a bigger planet and Mercury, Venus, Earth and Mars are smaller bodies which were created by division of the bigger planet.

Merits :

- This hypothesis does explain the material variety of planets.
- This hypothesis justifies the angular momentum of the planets of the solar system.
- This hypothesis does not deal with imaginary celestial bodies. A large number of supernova can be seen in the universe. One such supernova can be seen in the Carb Nebula. It is about twice as larger as the earth but is thirty thousand times brighter than the sun. Its surface temperature is about five lakh degree Celsius.

Demerits :

- It fails to explain the peculiar arrangement of planets on the basis of their size.
- Formation of planets and satellites is not very clear.
- It does not explain the rotation of planets in the same direction and their revolution in the same plane.

1.3.2.2 Dualistic Hypothesis

1.3.2.2.1 Tidal Hypothesis of James & Jeffrey

Sir James Jeans and Prof. Harold Jeffreys, the British scientists put forward a tidal hypothesis in 1919 to meet the objections against Laplacian hypothesis and the shortcomings of tidal theory of Chamberlin and Multon. Jeans and Jeffreys suggested the approach of a passing star which produced the tidal effect. It may be pointed out that Prof. Harold Jeffreys modified this theory in 192 9 in his own way. His modified theory was also full of many shortcomings.

It may be pointed out that the passing star was much larger than the sun in size and mass. Under the gravitational pull of the passing star the sun would be deformed into a lobate body in the direction of the former. The passing star raised enormous tides and pulled outward gaseous filament of solar matter as the star approaches nearer and nearer. By the time the star reached the farthest position, the filament had so much enlarged itself that ultimately it was detached from the sun.

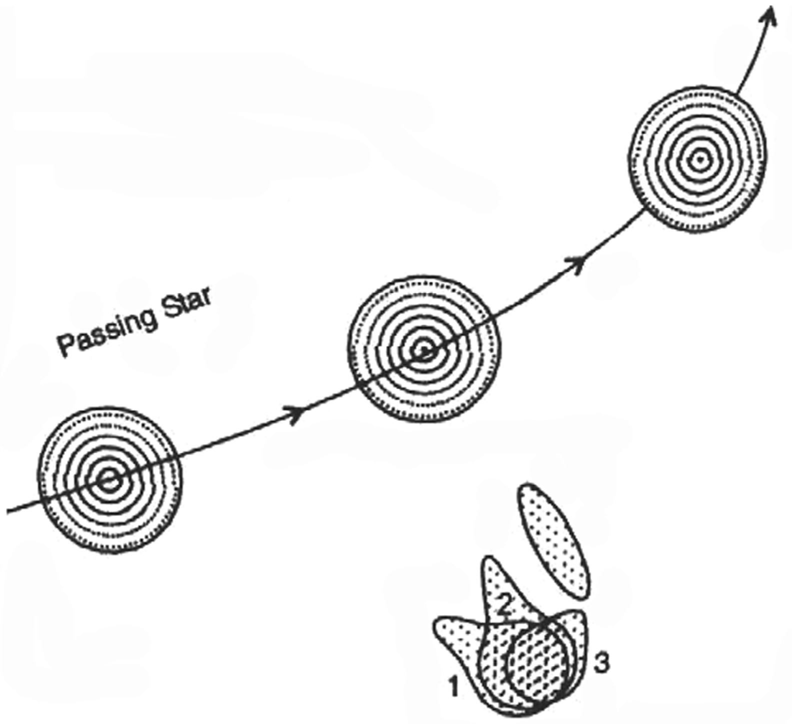


Figure 1.1: Tidal Hypothesis of James & Jeffery

The filament being so massive, it is able to maintain itself without dispersal. Gravity would cause the formation of knots. The passing star gives a rotary motion to the filament. It is noteworthy that the filament was considered to be the building material of planets of the solar system. The filament was given a rotary motion by the passing star. As the star passed into space the filament was left behind in the gravitational range of the sun. So, the filament revolves round the sun. As the star recedes, the filament breaks up and the planets condensed out of it. When the star was nearest the sun, its pull was greatest, so the filament would naturally be thickest in the middle. The planets, therefore, would be larger than those at the outer ends of the filament. In this way the solar system came into existence. The planets thus formed retain the angular momentum imparted by the passing star. The planets revolve round the sun in the same plane which contained the sun and the passing star.

As regards the origin of satellites, the tidal theory of James Jeans suggests that the planets which were bigger in size would remain in gaseous state for longer time and they took longer time to cool. On the contrary, the planets that were smaller in size took less time to cool and condense. The gravitational pull of the sun was more effective in raising small filaments from the outer surface of the bigger planets due to their gaseous form. Whereas the larger number of satellites were formed from the bigger planets, the smaller planets could produce lesser number of satellites. No satellites were formed from small planets located at the extreme end of the planetary system because they took very little time to come into solid form.

By the time the satellites were formed, their parent-planets were cooled to a liquid state. Therefore, it is possible that satellites were formed as liquid masses. According to this theory, the original orbits of the planets were eccentric, not circular, but the intruding star by its tidal effect might have catered solar matter round the sun in addition to raising the filament. The resistance offered by the scattered matter would have reduced eccentricity of the planetary orbits and made them circular.

Merits :

- This hypothesis does explain arrangement of planets.
- According to this theory the bigger planets had more mass and remained in gaseous state for a longer period than their small counterparts. Thus, larger number of satellites were formed from bigger planets while the smaller planets had to content with lesser number of satellites.
- This theory presumes that planets were formed from the filament which starting revolving around the sun after getting detached from it by the gravitational force of the approaching star. Consequently, the planets should also revolve around the sun. All the present planets are revolving around the sun in the direction of motion of the ejected filament. Also, the orbital plane of majority of the planets is the same. Leaving a few exceptions, majority of the planets are rotating in the same direction.

Demerits :

- Because of the vastness of the distances among stars in the universe, the fact of encounter of a star with the sun is a remote possibility

- Raising a filament of matter by a passing star may be possible, but the imparting of revolutionary motion to the filament or its constituents is improbable.
- The question of angular momentum, *i.e.*, the great distance of the outer planets from the sun is difficult to explain.

1.3.2.2.2 Planetesimal Hypothesis of Chamberlin and Multon

Chamberlin & Multon considered that a wandering star approached the sun, and a cigar-shaped extension of material was separated from the solar surface. As the passing star moved away, the material separated from the solar surface continued to revolve around the sun and slowly condensed into planets. Obviously, according to this hypothesis the origin of planets is supposed to be due to severe tidal eruption and disruption of some of the sun's mass. An approaching star caused the tidal eruption by its gravitational power. The disrupted solar matter was thrown to long distance from the sun. The larger nuclei of the tidal ejection gathered together. These larger bodies gathered smaller scattered bodies or planetesimal and eventually grew into the mature planets of the solar system. Planetesimal are the tiny planets which coalesced owing to gravitational attraction of collision.

According to this hypothesis "the total mass of the planets is only a smaller fraction (1/700) of the mass of the whole solar system, but they carry nearly 98% of its energy revolution" (Wooldridge & Morgan).

Merits :

The main merits of the hypothesis when it was presented were as follows :

- The earth grew bit by bit by accretion of planetesimal matter.
- When the mass of the earth became condensed and compacted, it developed internal heat. This created pocket of melting. Subsequently, there was differentiation of a metallic core and a stony outer crust.
- The constituents of the atmosphere and ocean also originated from the planetesimal.

Demerits :

- This hypothesis does not explain the number of planets in the solar system.
- Due to the collision of planetesimals, the orbit of the planets should not be near-circular as it is at Present.
- The hypothesis has been built on a catastrophic and extraordinary event. It is unreasonable to base any concrete scientific hypothesis on such a event.

1.3.2.2.3 The Binary Star Hypothesis by H. N. Russell

The principal weakness of the hypothesis that we have considered so far, is that they are unable to provide a satisfactory explanation for the great distance of the planets from the sun and their circular orbits round the sun. This difficulty can be removed if it is assumed that the materials which formed the planets were far removed from the sun from the very beginning or in other words, if it is assumed that the planets have not been from the sun. Accordingly, H.N. Russell suggested that there was another companion star of the sun and the two together formed a binary star or a twin-star system. A third star happened to pass close to the companion star of the sun and this resulted in the ejection of gaseous matter from the latter in the form of a filament which ultimately separated from it. The planets were formed from this gaseous filament of matter in course of time. In the beginning the planets were closer together and the satellites owe their birth to the mutual gravitational attraction between them. This third star was too far away from the sun to have any impact on the latter.

Merits :

- The suggestion that the primitive sun was a binary star can not be dismissed as mere imagination, because at least 10% of the stars in the universe are binary stars. In fact, in the opinion of some scholars the number of binary stars is probably 30% of the total.
- This hypothesis helps us to explain the great distance of the planets from the sun as well as their high angular momentum.

Demerits :

- The greatest weakness of the hypothesis is its inability to account for the removal of the sun's companion from its control and for the retention of the tidal filament which is later supposed to condense into planets and revolve round the sun. R.A. Lyttlenton (1936) has supported this hypothesis and has tried to show by mathematical calculations that is the possible under certain circumstances. If it is assumed that (a) the mass of the sun, the companion star as well as the third star was roughly equal (b) the distance of the companion star from the sun was 1700 million miles (c) the speed of revolution of the companion star round the sun was 6 miles per second and the speed of the third was at least 20 miles per second, and (d) the third star had come within a distance of approximately 3 to 4 million miles of the companion star. Under the above stated conditions, it is possible that tidal filaments will be ejected both from the companion star and the third star, the elliptic orbit of thew companion star will change into hyperbole orbit and it will escape from the gravitational control of the sun.
- Another objection raised against this hypothesis, is its failure to account for the present position of the planets, that is, their distance from the sun and their orbit, if it is assumed that the planets were formed at roughly equal distance from the sun as the hypothesis apparently seems to suggest.

1.4 Geological Time Scale

A critical analysis of the methods of finding out the age of the earth clearly shows that there is general disagreement among scientists on this subject. However. majority of the modern scientists are of the opinion that the age of the earth may vary from 3 to 5 billion years. Besides the scientific community believes that the earth has passed through certain geological processes marking a well- established geological time scale. The earth was a hot gaseous mass and remained so in the first billion years of its history. Since then, it has been cooling. In the process, it acquired liquid state and later on its outer surface solidified. Conditions suitable for earliest life forms to survive on the earth were created about 3,100 million years ago. However, man appeared on the earth at a much later stage. So, he knows very small part of the earth's geological history from direct observation. The rest is derived from the study of fossils.

The main purpose of studying the geological history of the earth is to establish the succession of geological events and to work out a 'geological time scale'. The geological time scale refers to the chronological programming of various geological forms and forms of life in the past according to their time and place of origin, evolution and extinct. In other words, this deals with the distribution of rock formations and animals since the beginning of life on the earth."

The first geological time scale was developed by Giovanni Arduina, an Italian scientist. in 1760 During the second half of the 19th century, steps were taken to unify the geochronological and stratigraphic subdivisions. For that purpose, the Geological Time Scale common for the whole world was adopted in 1881 at the second session of the International Geological Congress in Bologna. The scale has been modified and improved several times since then. On the geological scale, the longest time span is called an era which is divided into periods. The period in its turn is divided into epochs. This division is like years. months and days in a calendar.

The earth's crust consists of five major rock strata, each subdivided into minor strata, one lying on the top of the other. These sheets of rock were formed by the accumulation of mud or sand at the bottom of oceans. seas and lakes, and each contains certain characteristic fossils that serve to be identified as deposits made at the same time in different parts of the world. Based on the evidences of geological conditions and life in the past, the total span of geological time is generally divided into five eras. The geological time scale is customarily presented in the form of a table.

Table 1.2 : Geological Time Scale

Era	Period	Epoch	Time from beginning to recent (Millions of years)	Geological Conditions	Variety of biota (life)
Cenozoic (Age of mammals)	Quater-nary	Holocene (Recent)	0.025	End of last ice age. Climate became warmer with distinct climatic zones	Modern man appeared in the beginning of this period. Herbs dominant. Modern genera and species of animals and plants.
		Pleistocene	1.0	Four ice ages of the great ice age. Periodic continental glaciers. Cold and mild climate.	Development of modern vegetal and animal world. Expansion of herbs and decline of woody plants. Age of man, prehistoric man. Flourishing of mammals birds, fishes and insects but extinction of many large mammals
	Tertiary	Pliocene	12	Dry and cool climate, volcanic activity, rise of mountains in North America.	Expansion of herbs and grasslands, decline of forests. Mammal abundant. Emergence of man. Elephants, horses and camels almost similar to modern forms.
		Miocene	28	Moderate climate. Plains and grasslands developed.	Forests declined but grasslands spread. Evolution of mammals at its climax. Development of anthropoid apes (First man like apes).
		Oligocene	39	Warmer climate, low lying lands and mountain building.	Abundance of tropical forests. Flowering plants and monocotyledons common. Extensive flourishing of primitive mammals but extinction of archaic mammals. First apes and monkeys appeared.

Era	Period	Epoch	Time from beginning to recent (Millions of years)	Geological Conditions	Variety of biota (life)
		Eocene	58	Climatic belts well established.	Angiosperms and placental mammals diversified. Establishment of hoofed and carnivorous mammals.
		Paleocene	75	Formation of climatic belts. Mountain building activity.	Modernization of angiosperms. Archaic mammals dominant. Rise of modern birds, placental mammals and first primates.
Mesoaoic (Age of reptiles, eraus of medieval life)	Cretaceo	Late Cretaceous Early Cretaecous	189	Diverse climate. Formation of mountains and swamps	Rise of monocotyledons and decline of gymnosperms. Deciduous trees abundant. Extinction of dinosaurs and toothed birds. First teleost firshes and modern birds. Archaic mammals common.
	Jurassic	Late Middle } Jurassic Early	195	Warm climate Continents fairly high. Shallow seas	Extensive development of ammonites and belemnites. First angiosperms appeared. Cycads and conifers common. Flourishing of reptiles of land, in air and water. Dinosaurs dominant. Rise of first tooth birds. Insects abundant.
	Triassic	Late Middle } Triassic Early	230	Global tropical and subtropical climate. Continents elevated. Wide spread deserts	Extincition of seeds forms and primitive amphibians. Decline of gymnosperms. Rise of first dinosaurs and egg laying mammals.
Proterozic (Era of Ancient life)	Permian	Late Permian Early Pemlian	280	Rise of continents. Arid climate, Glaciation in southern hemisphere	Decline of primitive plants. Trilobities extinct. Reptiles abundant. Decline of amphibians. Therapsids appeared.

Era	Period	Epoch	Time from beginning to recent (Millions of years)	Geological Conditions	Variety of biota (life)
	Carbon-iferous	Upper Corbonife rous Lower Carbonife rous	320 345	Uniform climate-first humid and later cooler. Expansion of tropical seas	Luxuriant forest growth. First reptiles. Appearance of winged insects. Foramini ferous spiny brachiopods and cronoid abundant. Ancient sharks and amphibians present. Few corals and trilobities.
	Devo-nian	Late Middle } Devonian Early	402	Warm and semi-arid climate. Rise in temperature of inland seas. Mountains appeared	First forests grew. First amphibians. Flourishing of armed fishes. Crinoids, corals, brachiopods abundant. First ammonites. Decline of trilobities.
	Silurian	Late } Silurian Early	425	Mild cool climate. Rise of lands. Flat continents. Extensive continental seas	First land plants (cratimosses) algae dominant. Origin of insects. Origin of jawed fishes. Abundance of coraly, brachiopoods and crinoid millipeds present. Decline of trilobities.
	Ordovi-cian	Late Middle } Ordovician Early	500	Climate warmer. Expansion of Oceans	Algae, fungi, bacteria present. First plant fossils available. Origin of jawless armoured fishes (first, vertebrates) crinoids nautiloid cephalopods, ostracods, grapolites, brachiopods, molluscs and trilobites abundant.
	Cam-brian	Late Middle } Cambrian Early	600	Warm mild climate. Low land submerged	Dominance of triloblteі among established invertebrate groups. Also, brachiopods. calcareous sponges corals, diversified mollusks present. Marine algae abundant.

Era	Period	Epoch	Time from beginning to recent (Millions of years)	Geological Conditions	Variety of biota (life)
Proterozic (Era of Ancient life)			2000	Great volcanic eruptions. Extensive Great volcanic eruptions. Extensive erosion. Repeated glaciations, cool climate	Primitive aquatic plants (algae, fungi, bacteria), calcareous deposits by algae. Graphite deposits. Origin of simple marine invertebrates (worm burrows).
Archeozoic (Dawn of life)			3600	Great volcanic activity. Some sedimentary depostion, extensive erosion	Indirect evidence of beginning of life. No recognizable fossils. Calcareous deposits by algae some 2600 million years old. Graphite deposits.

[Source : Physical Geography, D. R. Khullar]

1.5 Internal Structure of the Earth

Though the study of constitution of the interior of the earth is outside the domain of geography but its elementary knowledge is necessary for the geographers because the nature and configuration of the reliefs of the earth's surface largely depend on the nature, mechanism and magnitude of the endogenetic forces which originate from within the earth. It is decidedly true that it is very difficult task to have accurate knowledge of the constitution of the earth's interior because it is beyond the range of direct observation by man but recently seismology has helped to have some authenticated knowledge about the mystery of the earth's interior. The sources which provide knowledge about the interior of the earth may be classified into 3 groups.

1. Artificial source
2. Evidences from the theories of the origin of the earth
3. Natural sources

1.5.1 Artificial Sources

1.5.1.1 Density

Numerous incurrences can be drawn about the constitution of the interior of the earth on the basis of density of rocks, pressure of super incumbent load (weight of overlying rocks) and increasing trend of temperature with increasing depth inside the earth. It is commonly believed that the outer thinner part of the earth is composed of sedimentary rocks the thickness of which ranges between half a mile to one mile (0.8 km to 1.6 km). Just below this sedimentary layer there is the second layer of crystalline rocks, the density of which ranges between 3.0 and 3.5 at different places. The average density of the whole earth is about 5.5. Thus, it appears 18 that the density of the core of the earth will be, without doubt, more than 5.5. Generally, the density of the core of the earth is around 11.0. Cavendish attempted to calculate the average density of the earth in 1798 on the basis of the Newton's gravitational law. According to him the average density of the earth is 5.48. Poynting calculated the average density of the earth as 5.49 g cm^{-3} in the year 1878. Since 1950 several attempts are being made to calculate the density of the earth on the basis of satellites. The satellite studies have revealed the following results about the density of the various parts of the earth-average density of the earth = 5.517 g cm^{-3}, average density of the earth's surface = 2.6 to 3.3 g cm^{-3} and average density of the core = 11 g cm^{-3}. Thus, it is proved that (l) the density of the core of the earth is highest of all parts of the earth.

1.5.1.2 Pressure

Now question arises, what is the reason for very high density of the core? previously it was believed that very high density of the core was because of heavy pressure of overlaying rocks. It is common principle that pressure increases the density of rocks. Since the weight and pressure of rocks increase with increasing depth and hence the density of rocks also increases with increasing depth. Thus, it is proved that (2) very high density of the core of the earth is due to very high pressure prevailing there because of super incumbent load. This inference is proved wrong on the ground that there is a critical limit in each rock beyond which the density of that rock cannot be increased in spite of increasing pressure therein. It may be, thus, forwarded that (3) very high density of the core of the earth is not because of very high pressure prevailing there. If the high density of the core of the earth is not because of high pressure of overlying rocks then (4) the core must be composed of intrinsically heavy metallic materials of high density. The experiments have revealed that the core of the earth is made of the mixture of iron and nickel. This inference is also validated on the basis of geocentric magnetic field. The metallic core is surrounded by a zone of such rock materials, the upper part of which is composed of crystalline rocks.

1.5.1.3 Temperature

It is evident on the basis of information available from the findings of bore holes and deep mining that temperature increases from the surface of the earth downward at the rate of 2° to 3°C for 100 metres. It may be pointed out that it becomes very difficult to find out the rate of increase of temperature beyond the depth of 8 km. The rate of increase of temperature in the continental crust has been calculated based on geothermal graphs and the following generalization has been made. In the tectonically active areas (like the Basin and Range Province of the USA) temperature remains 1000°C at the depth of 43 km from the surface of the earth while the temperature remains only 500°C at the depth of 40 km from the surface in tectonically stable areas. This information provides significant knowledge about the nature and behaviour of the continental crust. It is evident that high temperature of 1000°C at the depth of 43 km in the tectonically active areas is nearer to the initial melting point of the rocks of lower crust and mantle mainly basalt and peridotite.

The temperature of the upper part of the magma slab representing the upper portion of the Oceanic crust has been estimated to be 0°C whereas the temperature of the lower part of the magma slab which comes in contact with the asthenosphere remains 1200°C which is quite nearer to the melting point. If we believe the rate of general increase of temperature with increasing depth the temperature should be around 25,000°C at the depth of 2,900 km but under such circumstances most part of the earth would have melted but this has not so happened. It is evident from this discussion that most parts of the radioactive minerals are concentrated in the uppermost layer of the earth. This fact explains the situation of high temperature in the continental crust as described above because disintegration and decay of radioactive minerals generate more heat in the crustal areas. It, thus, appears that the rate of increase of temperature downwards decreases with increasing depth. The following facts may be presented about the thermal condition of the interior of the earth.

(i) The asthenosphere is partially molten. The temperature is around 1100°C at the depth of 100 km which is nearer to initial melting point.

(ii) The temperature at the depths of 400 km and 700 km (from the earth's surface) has been estimated to be 1,500°C and 1,900°C respectively.

(iii) The temperature at the junction of mantle and outer molten core standing at the depth of 2,900 km is about 3700°C.

(iv) The temperature at the junction of outer molten core and inner solid core standing at the depth of 5,100 km is 4,300°C.

1.5.2 Evidences from the Theories of the Origin of the Earth

Various exponents of different hypotheses and theories of the origin of the earth have assumed the original form of the earth to be solid or liquid or gaseous. According to the 'planetesimal hypothesis' the earth was originated due to accretion and aggregation of solid dust particles known as planetesimals'. Based on this corollary the core of the earth should be in solid state. According to the **'tidal hypothesis'** the core of the earth should be in liquid state because the earth has been taken to have been formed, according to this hypothesis, from the tidal materials ejected from the primitive sun. According to the **'nebular hypothesis'** of Laplace the core of the earth should be in gaseous state. Zoeppritz and Ritter have opined that the core of the earth is made of gases but this concept may not be accepted because if we assume the core of the earth in gaseous state many more problems will emerge. There may be only two possibilities viz. either the core may be in solid state or liquid state. This problem would be dealt with while dealing with the evidences of seismology.

1.5.3 Natural Sources

1.5.3.1 Vulcanicity

Some scientists believe on the basis of upwelling and spread of hot and liquid lava on the earth's surface during volcanic eruption that there is at least such a layer below the earth's surface which is in liquid state. Such molten layer has been termed as **'magma chamber'** which supplies magma and lava during volcanic eruptions. It may be, thus, surmised, on the basis of above connotation, that some part of the earth should be in liquid state but this inference is refuted if one considers the increasing pressure with increasing depth inside the earth. It is known to all that increasing pressure increases the melting point of the rocks. Thus, the inner part of the earth may not be in molten state in spite of very high temperature prevailing therein because the enormous weight and pressure of the overlying materials (super incumbent load) increases the melting point of the rocks. It, thus, appears that the core of the earth should be in solid state. Now question arises, where hot and liquid lavas come from during volcanic eruption? It may be pointed out that when the pressure of super incumbent load is released due to fracturing and faulting in the crustal surface, the melting point of underlying rocks is reduced (lowered) and thus the rocks are instantaneously melted because required degree of high temperature is already present there. It, thus, appears that no authenticated knowledge about the composition of the earth's interior is obtained from the evidences of volcanic activities.

1.5.3.2 Evidence of Seismology

Seismology is the science which studies various aspects of seismic waves generated during the occurrence of earthquakes. Seismic waves are recorded with the help of an instrument known as seismograph. It may be pointed out that seismology is the only source which provides us authenticated information about the composition of the earth's interior. The place of the occurrence of an earthquake is called 'focus' and the place which experiences the seismic event first is called 'epicentre', which is located on the earth's surface and is always perpendicular to the 'focus'. On the other hand, the focus or the place of the origin of an earthquake is always inside the earth. The deepest focus has been measured at the depth of 700 km from the earth's surface. The different types of tremors and waves generated during the occurrence of an earthquake are called 'seismic waves' which are generally divided in 3 broad categories *e.g.*, primary waves, secondary waves and surface waves.

(i) **Primary waves :** also called as longitudinal or compressional waves or simply 'P' waves, are analogous to sound waves wherein particles move both to and fro from the line of the propagation of the ray. P waves travel with fastest speed through solid materials. Though these also pass-through liquid materials but their speed is slowed down.

(ii) **Secondary waves :** are also called as transverse or distortional or simply S waves. These are analogous to water ripples or light waves wherein the particles move at right angles to the rays. S waves cannot pass through liquid materials.

(iii) **Surface waves :** are also called as long period waves or simply L waves. These waves generally affect only the surface of the earth and die out at smaller depth. These waves cover longest distances of all the seismic waves. Though their speed is slower than P and S waves but these are most violent and destructive.

When an earthquake occurs the seismic waves are recorded at the epicentre with the help of seismograph. In the beginning a few small and weak swings are recorded. Such tremors are called ***'preliminary tremors'.*** After a brief interval the '***second preliminary tremors'*** are recorded and finally the 'main tremors' or strong waves are recorded.

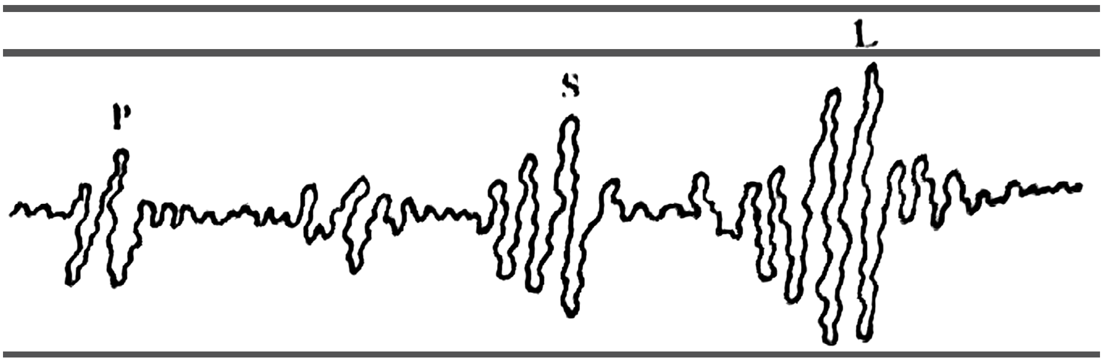


Figure 1.2 : Seismic waves

1.5.3.3 Recent Views :

The aforesaid views about the composition and structure of the earth 's interior have now become obsolete. The scientific study and analysis of various aspects of seismic waves (mainly velocity and travel paths) of natural and man-induced earthquakes have enabled the scientists to unravel the mystery of the earth's interior based on authentic information. Three zones of varying properties have been identified in the earth on the basis or changes in the velocity of seismic waves while passing through the the earth (fig 1.3) *e.g.* crust, mantle and core. It may be pointed out that there is still difference of pinions about the thickness of these zones, mainly about the thickness of the crust. Various sources put the thickness of the crust between 30 km and 100 km. On the basis of the change in the velocity of seismic waves crust is further divided into (i) upper crust and (ii) lower crust because the velocity of P waves suddenly increases in the lower crust. For example, the average velocity of P waves in the upper crust is 6.1 km per second while it becomes 6.9 km per second in the lower crust. Fig. 1.3 depicts the different velocity of P and S waves in different parts of the earth and the relationship between velocities of seismic waves and different zones of the earth.

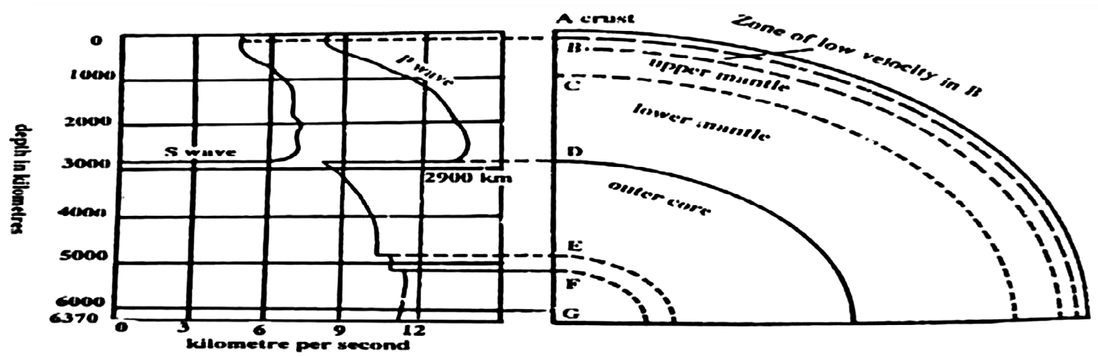


Figure 1.3 : Presentation of velocities of seismic waves from the crust of the earth to its interior and rela1ionsihps between the velocities of seismic waves and different zones of the earth (after K. E. Bullen).

(1) CRUST

The average density of the outer and lower crust is 2.8 and 3.0 respectively. It may be pointed out that in the beginning vast difference between structure and composition of the upper and lower crust was reported by the scientists but now the evidences of seismology have revealed almost identical structure and composition of these two subzones of the crust. The difference of density between the upper (2.8) and lower crust (3.0) is because of the pressure of supper incumbent load. The formation of the minerals of the upper crust was accomplished at relatively lower pressure than the minerals of the lower crust.

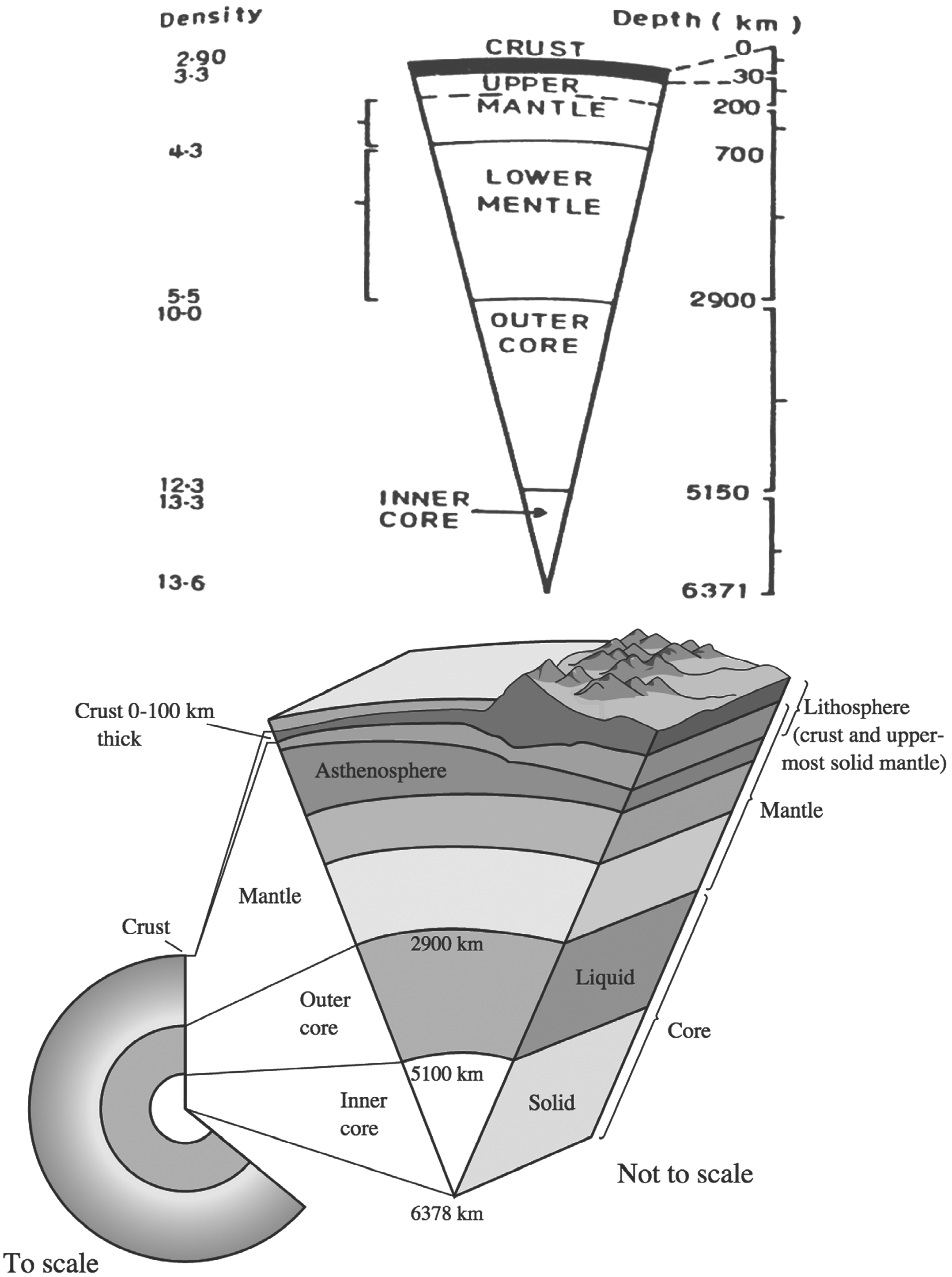


Figure 1.4 : Internal structure of the earth

(2) MANTLE

There is sudden increase in the velocity of seismic waves at the base of lower crust as the velocity of seismic waves is about 6.9 km per second at the base of lower crust but it suddenly becomes 7.9 to 8.1 km per second. This trend of seismic waves denotes discontinuity between the boundaries of lower crust and upper mantle. This discontinuity was discovered by A. Mohorovicic in the year 1909 and thus it is called as **'Mohorovicic discontinuity'** or simply **'Moho discontinuity'.** The mantle having mean density of 4.6 g cm^{-3} extends for a depth of 2900 km inside the earth. It may be mentioned that the thickness of the mantle is less than half of the radius of the earth (6371 km) but it contains 83 per cent of the total volume and 68 per cent of the total mass of the earth. Previously the mantle was divided into two zones on the basis of changes in the velocities of seismic waves and density *e.g.* (i) upper mantle from Moho discontinuity to the depth of 1000 km and (ii) lower mantle from 1000 km to 2900 km depth but now the mantle is divided on the basis of the information received from the discovery of the International Union of Geodesy and Geophysics into 3 sub-zones *e.g.* (i) first zone extending from Moho discontinuity to 200 km depth, (ii) second zone extending from 200 km to 700 km depth and (iii) third zone extending from 700 km to 2900 km depth. The velocity of seismic waves relatively slows down in the uppermost zone of the upper mantle for a depth of 100 to 200 km (7.8 km per second). This zone is called the zone of low velocity. Mantle is believed to have been formed largely of silicate minerals rich in iron and magnesium.

(3) CORE

The core, the deepest and most inaccessible zone of the earth, extends from the lower boundary of the mantle at the depth of 2900 km to the centre of the earth (up to 6371 km). The mantle-core boundary is determined by the **'Weichert-Gutenberg Discontinuity'** at the depth of 2900 km. It is significant to note that there is pronounced change of density form 5.5 g cm^{-3} to 10.0 g cm^{-3} along the Gutenberg Discontinuity. This sudden change in density is indicated by sudden increase in the velocity of P waves (13.6 km per second) along the mantle-core boundary or Gutenberg Discontinuity. The density further increases from 12.3 to

13.3 and 13.6 with increasing depth of the core. It, thus, appears that the density of the core is more than twice the density of the mantle but the volume and mass of the core are 16 per cent and 32 per cent of the total volume and mass of the earth respectively.

The core is further divided into two sub-zones *e.g.*, **outer core** and **inner core**, the dividing line being at the depth of 5150 km. S waves disappear in this outer core. This means that the outer core should be in molten state. The inner core extends from the depth of 5150 km to the centre of the earth (6371 km). This lowermost zone of the interior or the earth is in solid state, the density of which is 13.3 to P waves travel through this zone with the speed of 11.23 km per second. It is generally believed that the core is composed of iron and nickel but according to the second view point the core may be formed of silicates. It is also believed that after disintegration on high pressure the electronic structures have changed into heavy metallic materials, thus the density of the core has increased. According to the third view point initially the core was composed of hydrogen but later on hydrogen was transformed into metallic materials due to excessive pressure (over 3 million atmosphere). This possibility is questioned on the ground that though the transformation of silicate or hydrogen due to very high pressure in the core may be believed tentatively but this process cannot increase the density of the core as high as it is at present. For example, the planet Mercury is smallest of all the planets of our solar system but its density is highest of all the planets. It may be argued that least compression and pressure cannot generate highest density in the core of Mercury. Most of the present-day geophysicists and geochemists believe that the core is made of metallic materials mainly iron and nickel.

1.6 Continental Drift

Continental Drift is the gradual movement of the continents across the Earth's surface through geological time. This concept is based on a premise that all the continents were once joined together as a single huge continental landmass which has rifted and drifted apart over the Earth's surface. The movement was considered as the primary factor in explanation of climatic changes, formation of landforms such as mountains, islands, volcanoes *etc.*

The concept of continents 'drift' was first proposed by Abraham Ortelivs in 1596. Then FB Taylor postulated his concept of "Horizontal displacement of Continents" in the year 1908. But the Continental Drift Theory was mainly developed by Alfred Wegner in 1912, it was based on the works of a host of scientists such as geologists, geophysicists and others.

1.6.1 Continental Drift Theory of Alfred Wegner

Alfred Wegner, a German climatologist, propounded the Continental Drift Theory in 1912. It came into light in 1922 in a book titled, "**Die Entstehung der Kontinnente and Ozeane**" which was translated to English in 1924 named as "**The Origin of Continents and Oceans**". Wegner, being a climatologist, needed to explain the climatic changes that occurred throughout the past history of Earth.

He explained the climatic changes, occurring on the surface of the Earth, in two ways-

- Continents remained stationary and climatic zones shifted from one region to another.
- Climatic zones remained stationery and continents displaced.

Assumptions

- Continents mass was made up of SiAl and Oceanic crust was made up of SiMa.
- Continents mass floated over oceanic crust with minimum resistance between them.
- There was a huge united landmass named Pangea in Carboniferous period and it was surrounding by a water body called Panthalassa.

Forces and Processes

- According to Wegner, the main forces responsible for the movement of continental landmasses were Buoyancy force, Differential gravitational force and Tidal force.

- The continental landmasses, floating over the oceanic crust moved in two directions towards the Equator and Westwards.
- Equator ward movement was under Buoyancy and Differential gravitational force. The westward movement was under Tidal force.
- Pangea landmass was broken attitudinally into two parts namely northern part was Angaraland and southern part was Gondowanaland respectively. The intervening space between two landmasses came to be known as 'Tethys Sea'.
- Gondowanaland, during Cretaceous period, split into Indian Peninsula, Madagascar, Australia, Antarctica, Africa and South America.
- Angaraland split into two continents. Namely North America and Eurasia.
- The 'S'-shape of Atlantic is due to differential movement of North and South America. Indian Ocean was formed due to Northward movement of Indian peninsula. Remaining portion of Tethys became Mediterranean Sea. Arctic was formed due to movement of continental blocks towards North Pole.

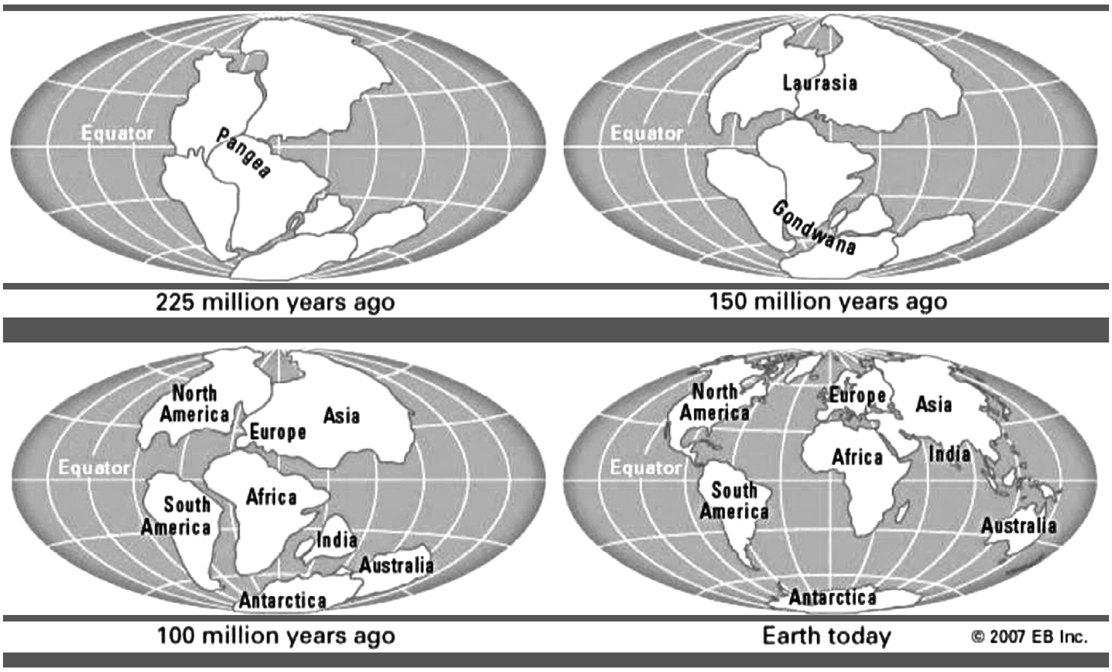


Figure 1.5 : Different stages of landmass and water distribution of the world

1.6.2 Evidence in Support of the Continental Drift Theory

Wegner cited various evidences to show that the continents could have been close together in the past as Pangea. The evidences are-

(i) **Juxta fix of Continents :** The shorelines of Africa and South America facing each other have a remarkable and unmistakable match. Thus, there is a geographical similarity between the two continents. They could fit like pieces of a puzzle.

(ii) **Structural and Stratigraphic Evidences :** The radiometric dating methods developed in the recent period have facilitated correlating the rock formation from different continents across the vast ocean. In north-western Africa and Eastern Brazil both 550 million years old rocks lie adjacent to rocks dated more than 2 billion years.

(iii) **Fossil Evidences :** Mesosaurus was an aquatic reptile adapted to shallow brackish water. The skeletons of these are found only in localities- the southern cape province of South Africa and Iraver formation of Brazil.

(iv) The fossil fern, glossopteris, is widely distributed in Africa, Australia, India, South America *etc.* country.

(v) **Paleoclimatic Evidences :** layers of glacial deposits *i.e.*, tillites, striations and grooved marks are found in tropical regions of South America, South Africa Australia and India.

(vi) **Tillite :** It is the sedimentary rock formed out of deposits of glaciers. Counterparts of this succession are found Africa, Falkland Island, Madagascar, Antarctica. It proves paleoclimates and drifting of continents.

(vii) **Placer Deposits :** Occurrences of rich placer deposits of gold in Ghana coast and the absolute absence of source rock in the region. Also, presence of gold bearing veins in Brazil show that obviously gold deposits of Ghana are derived from Brazilian plateau when they were together.

(viii) **Geological Similarity :** The Appalachians of North America are similar to mountain systems of Ireland, Wales and North-Western Europe.

1.6.3 Limitations of Continental Drift Theory of Wegner

Although Alfred Wegner spoke of the first the continental drift in 1912, which was translated in English in 1924 and since, then there has been a storm of controversy in the expert communities. Contemporary geologist such as Washington, Willis, Jeffreys have not accepted this theory. They criticized this theory in many ways.

(i) The forces, Differential gravitational force, Buoyancy force and Tidal force were not sufficient enough to drift the continents to thousands of km. If these forces were so enormous in their magnitude and all the continents would be concentrated near Equator.

(ii) Wegner's theory has several contradictions. In the earliar part he stated that SiAl is floating over SiMa with very less resistance. But later, distributing the formation of mountains, he describes the friction between SiAl and SiMa as the cause of formation of mountains.

(iii) Wegner did not describe the situation in pre-carboniferous times. Many questions still remain unanswered such as – Why the Pangea was intact in pre-carboniferous period? Why did the continental drift not start earlier?

(iv) Wegner did not describe the correct sequence and chronology of displacement of continents.

It may be concluded that even if all the matter of his theory is wrong, geologists and others can but remember that it is largely to him that we owe our more recent views on world tectonics. Though most point of Wegner's theory was rejected but its central theme of horizontal displacement was retained. In fact, the postulation of Plate Tectonic Theory after 1960 is the result of this Continental Drift Theory of Wegner. Wegner is thus, given to credit to have started thinking in this precarious field.

1.7 Mountain Building

Orogeny is the geological term for Mountain Building. The term was coined by the American geologist GK Gilbert in 1890, to describe the process of Mountain Building. Gilbert originally coined the term for the fold mountain belts of Rockies and Alps. The term cannot be applied to ocean ridges and rises which are submerged under seas. *i.e.*, submerged mountains, which originate through processes quite distinct from those rich produced mountain chains such as the Rockies and the Alps.

1.7.1 Types of Mountains

- **Fold Mountains :** They form as a result of compressive action on thickly bedded sedimentary layer. All the great mountains on the Earth such as Himalayas, Alps, Rockies and Andes are of this type.
- **Volcanic Mountains :** They are formed as a result of constant accumulation of volcanic material, lava and pyroclasts around a volcanic vent until a height is reached. Mountain Vesuvius, Mountain Etna, Mountain Fujiyama *etc* are of this type of Mountain.
- **Block Mountains :** They are tabular shaped mountains with flat tops that result from vertical upliftment of blocks along faults or are left elevated by the sinking of the surrounding areas. The various examples are Vosges, Black Forest *etc.*
- **Relict or Residual Mountains :** They are the remnants of former old mountains and plateaus which have been subjected to severe denudation, thus exposing the base of mountains. The Aravallis form a very good example of such types of mountains.

1.7.2 Mountain Building with reference to Plate Tectonics

The rigid lithospheric slabs or rigid and solid land masses having a thickness of about 100 km composed of Earth's crust and some portions of upper mantle are technically called 'Plates'. The term 'plate' was first used by Canadian geologist J. T. Wilson in 1965.

The whole mechanism of the evolution, nature and motion and resultant reactions of plates is called "Plate Tectonics". According to plate tectonic theory mountains are found due to collision of two convergent plates. Mountains are always formed along destructive plate boundaries. It is obvious that the process of mountain building is associated with destructive plate boundaries of two convergent plates.

The convergence and consequent collision of plate boundaries occurs different mountains. These collisions are

1.7.2.1 Continent-Ocean Collision

The collision of continental and oceanic convergent plates results in the formation of Cordillera type of folded mountain. The major events in the evolution of mountain belt by continent-ocean collision are—

1. A considerable thickness of sandstone, shale and lime stone accumulates in the miogeocline along the continental margins. At the same time, deep marine sediments accumulate in the deep ocean basin.
2. As the plate converge, the buoyant granitic mass of the continental crust being of lower density, overrides the adjacent oceanic plate.
3. As the convergence proceeds, the deep marine sediments on the oceanic plate are crumpled and deformed.
4. Then, the thick sequence of geoclinal sediments along the continental margins are compressed and deformed.

Explanation with Example : The Rockies and Andes mountains were formed due to subduction of the Pacific Ocean plate under the American continental plate. The pacific oceanic plate heavier due to denser materials is subducted below the light denser American continental plate. The sediment deposited on the American continental margins are squeezed and folded due to compressive forces and formed Rockies and Andes Mountains. Continent- Ocean collision and mountain Formation The Appalachian Mountain of the Eastern United States was deformed during late Paleozoic is this type of mountain building.

1.7.2.2 Continent-Continent Collision

The continent-continent occurs, when two continental plates collide. The major events in the generation of mountain belts by continent-continent collision are

(i) Geoclinal sediments occur along the margins of each continent.

(ii) The wedge of sediments along the margins of the continent are deformed above the subduction zone as the ocean basin decreases in size.

(iii) As the continents approach each other before colliding, segments of remaining ocean crust are deformed by over thrusting and are finally squeezed between the converging plates.

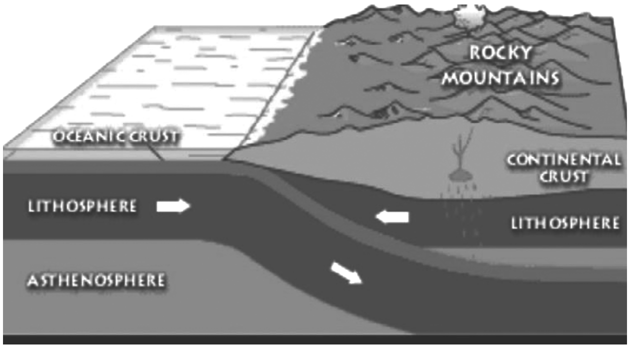


Figure 1.6 : Continent-Continent Collision

(iv) The oceanic slab descending into the mantle, becomes detached and sinks independently. When the slab has been consumed, the volcanic activities and earthquakes generated by it.

(v) As resisting forces build up, convergence stops, the mountain belt erodes and adjusts isostatically.

(vi) The welding together of two large continents produces a single large continental mass with internal mountain range.

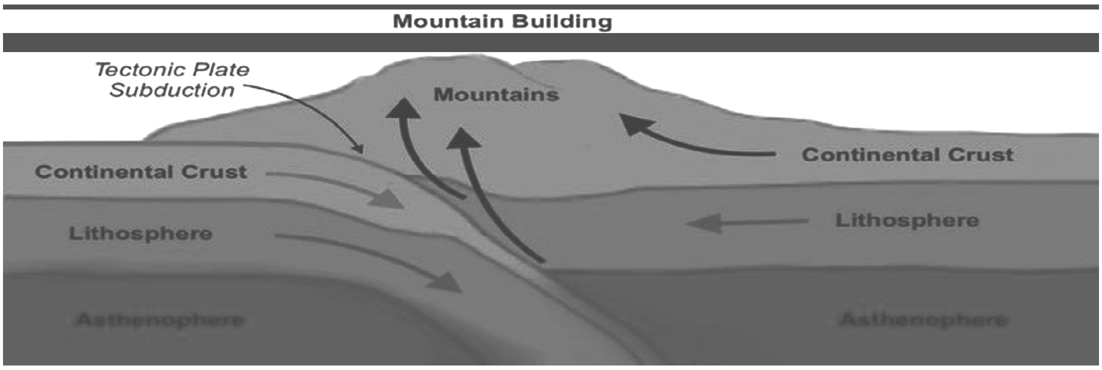


Figure 1.7 : Continent- Continent collision and formation of Mountains

Explanation with Example : The geosynclines sediments of Tethys Sea were squeezed and folded into Alpine-Himalayan Mountain chains due to lateral compressive forces caused by the convergence and collision of Eurasia and African-Indian continental plates during Cenozoic era. It may be pointed out that the formation of Alpine-Himalayan Mountain chains could be possible due to continued collision of continental plates and consequent orogenesis along several subduction zones for long period of time.

The other examples of this type of mountain buildings are the Alps, the Urals, the Atlas Mountain *etc.*

1.8 Landform Development due to Water

The running of water is involved in continuous erosion transportation and deposition of materials on the surface of the Earth. The landforms formed by progressive removal of rock mass are known as erosional landforms while landforms formed by deposition of different eroded materials are known as depositional landforms.

1.8.1 River Erosion

The erosional works of rivers depend upon the channel gradient, volume of water, velocity of flow, kinetic energy of river. The erosion also dependent upon the size of erosional tools known as river load. River is mainly involved in three types of erosion- (i) Vertical erosion, (ii) Lateral erosion and (iii) Headward erosion.

Erosional landforms : These are the erosional landforms of rivers—

(i) **V-Shaped Valley :** Valleys start as small and narrow rills, the rills will gradually develop into long and wide gullies, the gullies will further deepen, widen and lengthen to give rise to valleys. Depending upon dimensions and shape, many types of valleys like V-shaped, gorge, canyon *etc* can be recognized.

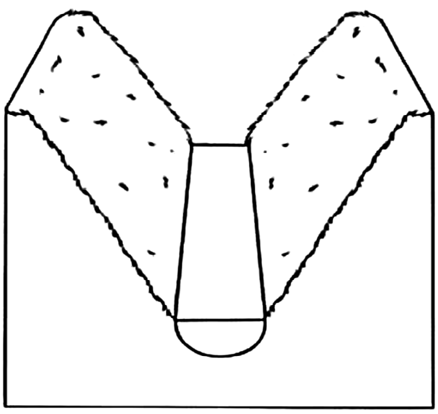


Figure 1.8 : V-Shaped Valley

(ii) **Gorge :** It has a steep precipitous wall within which a narrow river is confined. It can occur due to channel deepening as a result of recession of fall that has happened with Niagara gorge. Each continent has example of gorges. The Indus, Sutlej, Brahmaputra and Arun form gorges in the Himalayan region where they are antecedent streams.

(iii) **Canyon :** The narrowness of the valley is determined by both vertical erosion and humidity of the area. The Grant Canyon, Colorado is very deep but its wall is not vertical because it passed through an arid zone where frost weathering and other forms have tended to form the V shape.

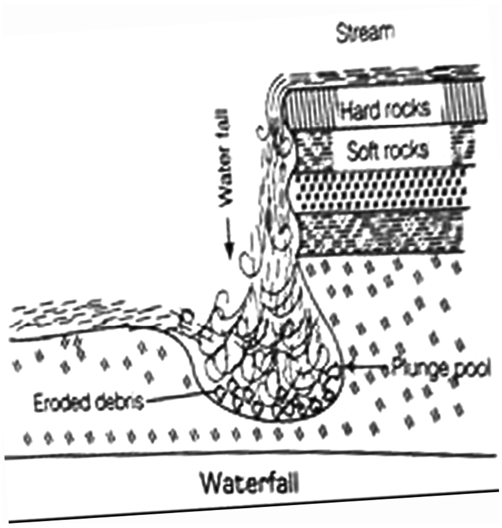


Figure 1.9 : Waterfall

(iv) Waterfall : When especially small rivers tumble down almost vertically from a height along its course, these form the waterfalls. A bar of resistant rock lying across a river valley leads to the formation of a waterfall, as in the case of Niagara Falls on Zambezi rivers in South Africa or a plunge down the edge of a plateau like Zaire of Africa.

(v) Hanging valley : In glaciated areas at points where tributary stream joins the main stream, the over-deepening of the main valley leaves the side valley hanging high above the valley of the master stream.

(vi) Potholes : Over the rocky beds of hill streams, more of less circular depressions called potholes form because of stream erosion aided by the abrasion of rock fragments.

(vii) Rapids : The occurrence of the band of a hard rock along the path of a river makes it jump over or rail downwards. This leads to the formation of rapids at place where the valley bottom offers greater resistance to the erosion than the strips above and below it.

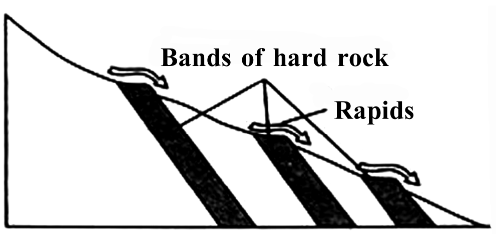


Figure 1.10 : Rapids

(viii) Plunge pools : At the foot of waterfalls, large potholes, quite deep and wide, forms because of the sheer impact of water and rotation of boulders. Such large and deep holes at the base of waterfalls are called plunge pools.

River Deposition

The factors such as deceasing channel gradient, decease in velocity, spreading of stream over a large area, obstruction in channel flow, decrease is discharge for creating river deposition and its landforms.

Depositional Landforms

(i) Meanders : Meanders are described as serpentine flow of rivers. Meanders are formed due to lateral erosion. The outer bank of a river is eroded due to lateral erosion and steep cliff is formed. The inner bank has depositional features.

(ii) Alluvial Fans : It is formed where a heavily laden stream reaches the plain, its velocity is checked, it widens and much of its load is deposited the deposited sediments spreads out as an Alluvial Fan.

(iii) Alluvial Cones : An alluvial cone is a type of alluvial fan, but one in which the slope angles are steeper and the deposited materials is generally coarser and thicker having been transported by ephemeral rivers.

(iv) Flood plain : A flood plain often is an area of marsh and numerous lakes, usually crescent shaped known as Ox-Bow lakes. These are the remnants of meanders that have been cut off. When the river is in flood, it spills over its channel and often covers the whole of the flood plain which it deposits sediment.

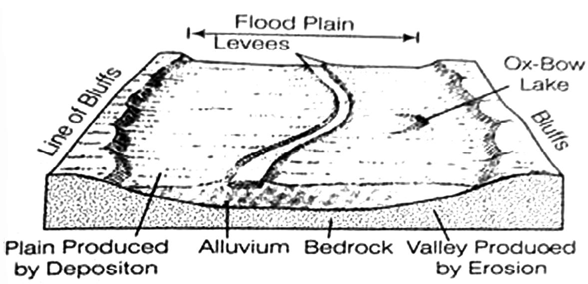


Figure 1.11 : Flood Plain

(v) Natural levees : Natural levees are found along the bank of large rivers. It is low, linear and parallel ridges of coarse deposits along the banks of rivers. The levee deposits are coarser than the deposits spread by flood waters away from the river.

(vi) Point Bars : Point bars are also known as member bars. They are found on the convex side of meanders of large rivers and are sediments deposited in a linear fashion by flowing waters along the bank.

(vii) Braided stream : The stream which thus, gets divided into a network of a channels forming bars of sand and islands is known as a Braided Stream.

(viii) Ox-Bow Lake : An ox-bow lake is a horse-shoe shaped lake at the side of a river. A long time ago, an ox-bow lake would have been a meander

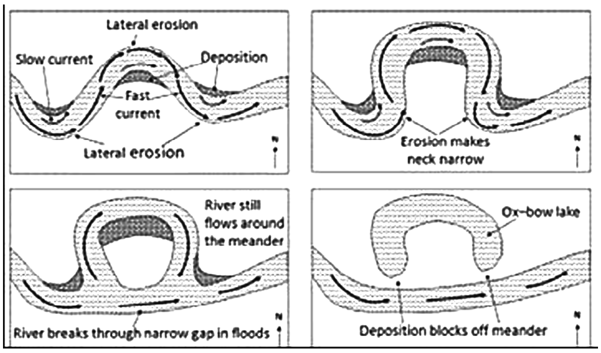


Figure 1.12 : Ox-Bow Lake

on the river. Over time the river eroded the land at the start of the meander. The meander curved almost to a circle. Then the river took the more direct path and went straight through. The meander was left as a curved lake beside the river.

(ix) Delta : The sediment deposited in the estuary builds up in layers to form a gently sloping platform. In time, the platform may extend up to the surface and above, when it is called Delta, delta is a low-lying swampy plain which gradually becomes colonized by various types of plants. There are three basic types of deltas –(a) Bird's foot, (b) Arcuate (c) Estuarine.

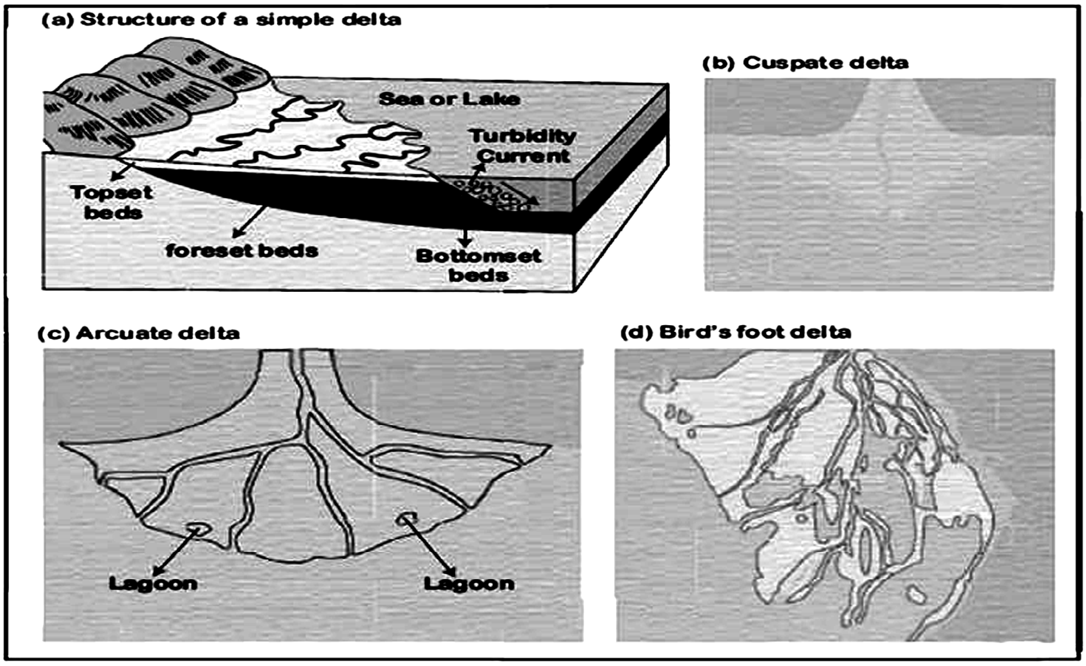


Figure 1.13 : Different types of Deltas

1.9 Landform Development due to Wind action

Wind is the most active agent in arid and semi-arid regions. It is involved in erosion, transportation and deposition of sediments which mainly includes sand. The work of Wind is greatly helped by the process of mechanical weathering active in such areas. The wind has a great scope of work with it by blowing over large areas free of any obstacles.

1.9.1 Wind Erosion

Wind Erosion is largely controlled and determined by—(i) wind velocity (ii) nature and amount of sand dust (iii) composition of rocks (iv) nature of vegetation (v) humidity, rainfall and temperature amount.

Wind erosion occurs as –

- **(a) Deflation :** The process of removal and blowing away of dry and loose particles is known as Deflation.
- **(b) Abrasion :** Sand blast action of sand grains against the rock surface known as Abrasion.
- **(c) Attrition :** Mechanical weak and tear of rock particles against each other is known as Attrition.

Landforms produced by Wind Erosion

These are the erosional landform of Wind—

- **(i) Deflation Hollows :** In the orid and semi-orid regions, where unconsolidated rocks are exposed, wind deflation over a prolonged period results in excavation of wide shallow basins or depressions called deflation hollows or blow acts. These develop where calcium carbonate is dissolved by ground water leaving loose sand grains, which are picked up and transported by wind.

Figure 1.14 : Mushroom rocks

- **(ii) Mushroom Rocks :** The rocks have broad upper portion in contrast to their narrow base and thus resembles an umbrella or mushroom. Mushroom rocks are also called pedestal rocks or pilzfelsen.

(iii) Pediments : Landscape evolution in desert is primarily concerned with the formation and extension of Pediments. Gently inclined rocky floors close to the mountains at their foot with or without a thin cover debris, are called Pediments.

(iv) Zeugens : Frost action and other agents break the hard rock capping and expose the points of weaknesses in the rock. It then becomes exposed to the abrasive action of the wind. When this process goes on, a tabular mass of resistant capping rocks lying upon softer rocks below it are formed straight side ridges called Zeugen.

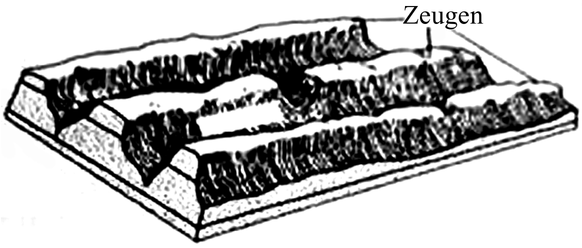
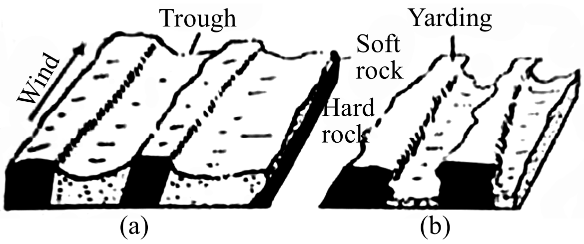


Figure 1.15 : Zeugens

(v) Yardangs : When the wind is blowing steadily over the hard and soft strata the softer materials are eroded forming passage ways between deeply undercut overhanging ridges. These rocks cuts ridges are called Yardangs. Yardangs commonly occur in clusters and are aligned to the direction of prevailing winds.



(a) Belts of softer rocks are abraded into throuths
(b) Hard rocks are under-cute and narrow

Figure 1.16 : Trough and Yardangs

(vi) Demoiselles : These are rock pillars which stand as resistant rocks above soft rocks as a result of differential erosion of hard and soft rocks.

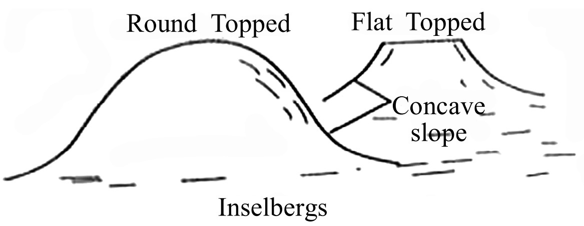


Figure 1.17 : Inselbergs

(vii) Inselbergs : The term was first used by Passarge in 1904, to delineate relict hills of South Africa. There has been a debate regarding the origin of these inselbergs as bornhardts.

1.9.2 Wind Deposition

Wind transports loosened sand and dust from one place to another for their deposition. Deposition of and obstructions caused by bushes, forests, marshes and swamps *etc.* sand and dust is deposited on both windward as well as leeward sides of obstructions.

Depositional Landforms Produced by Wind

These are depositional landform of wind—

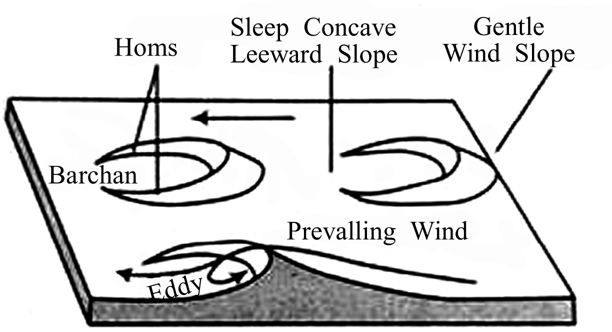


Figure 1.18 : Barchan

(i) Barchan : It is crescent shaped and lying at right angles to the prevailing wind with the horns pointing downward. A Barchan moves forward as grains of sand are carried up the windward face, which then slip down the leeward side. A Barchan ranges in height from a few meters to 30 m and may be wide as 400 m they occur singly and groups.

(ii) Loess : It is loose, unstratified, non-indurated, buff-coloured fire sediments, which are deposited at places far from their source of origin. Loess is of mainly two types *i.e.*, Desert Loess and Glacial Loess. Loess is known as 'liman' in France and 'Adobe' in America.

(iii) Seifs : They are Ridge-shaped with steep sides and lying parallel to the prevailing wind and parallel to each other. The crest of seif is sharp and over 100 m high and 150 km long and 25 m to 400 m wide. Some examples of seif dunes occur in the Great sand sea of Egypt and Libya, in the Namib Desert between Walvis Bay and Luderitz.

(iv) Sand Dunes : Sand dunes are heaps of sand found in deserts. Generally, their heights vary from a few meters to 20 m, but in some cases, dunes are several hundred meters high and 5 to 8 km long.

The formation of sand dunes requires –

Figure 1.19 : Sand Dunes

- Wind of high velocity
- Abundant sand
- Obstacles such as trees, bushes, rock outcrops, walls against, which dunes may settle
- Ideal place *i.e.*, dune complex, dune colony or dune chain.

1.10 Landforms Development Due to Glacier

Masses of the ice moving as sheets over the land flowing down the slopes of mountains are called 'Glacier'. The movement of glacier is slow unlike water flow. The movement could be a few centimetres to a few meters a day. Glacier moves basically because of the force of gravity.

1.10.1 Glacier Erosion :

Glacier erosion is caused by huge mass of ice sliding over the rocks and eroding them by its overweight, under the influence of gravity. Two principal processes are important abrasion and plucking.

(i) Abrasion : The grinding and cursing of rocks, is not accomplished by the ice itself as it is too soft, but by the rock debris frozen into the lower layers of the ice.

(ii) Plucking : Plucking occurs in response to the drag exerted by the moving ice on the bed rock. As the tensile strength of ice is not very great, plucking is most effective where the rock has been already weakened.

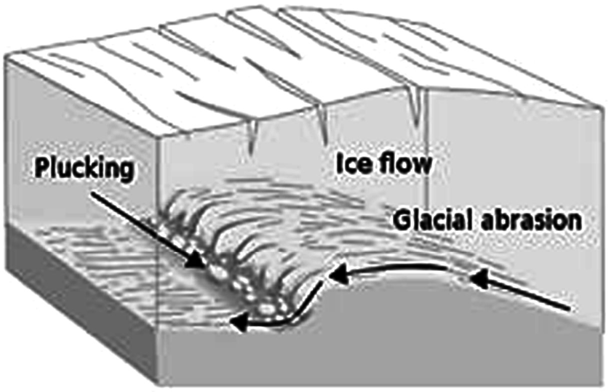


Figure 1.20 : Abrasion & Plucking

Erosional Landforms of Glacial Processes :

These are the erosional landforms of glacial regions—

(i) Cirques : These are the most common of landforms in glacial mountains. The cirques quite often are found at head of glacial valleys. They are deep, long and wide troughs or basins with very steep concave to vertically dropping high walls at its heads as well as sides. A lake of water can be seen quite often within the cirques after glacier disappears, are called 'Cirque Lakes'.

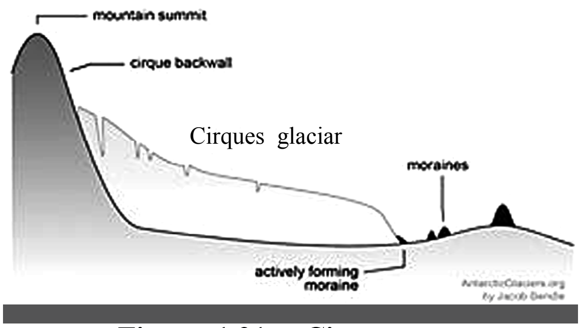


Figure 1.21 : Cirques

(ii) Sheep Rocks : A glacier does not avoid hard outcrops like cliffs falling along its path. It rides or flows over them so that the slope of the obstacle from the side the ice moved becomes gentler, while the other side where the ice flowed down is left rougher and steeper. These knolls having a Crag and the Tail and look like Sheep from a distance.

(iii) Rock Steps : There is very uneven excavation of the glacier floor depending on the nature and structure of bedrocks, thickness of the glacier and the rate of glacier flow. When the glacier come across a rock sequence, which is varying in resistance, the floor is excavated into a series of successive steps called Rock Steps.

Figure 1.22 : U-shaped Valley

(iv) U-Shaped Valley : Mountain glaciers cannot dig a new valley but deepen, straighten as well as widen the pre-exiting valley by eliminating irregularities and projecting spurs during its passage. The original V-shaped valley becoming narrower towards its head is turned into a U-shaped trough in this way.

(v) Glaciated Lakes : Long ribbon of finger shaped lakes gets excavated into the flow of glacial troughs as a result of ice erosion. The great lakes of North America have been formed by a similar deepening and damning.

(vi) Horns : Horns are through head ward erosion of the cirque walls. If three or more radiating glaciers cut head ward until their cirques meet, high sharp pointed and steep sided peaks called Horns are formed.

(vii) Glaciated valleys Troughs : Glaciated valleys are trough like and U-shaped valleys with broad floors and relatively smooth and steep sides. The valleys may contain littered debris or debris shaped as moraines with swampy appearance.

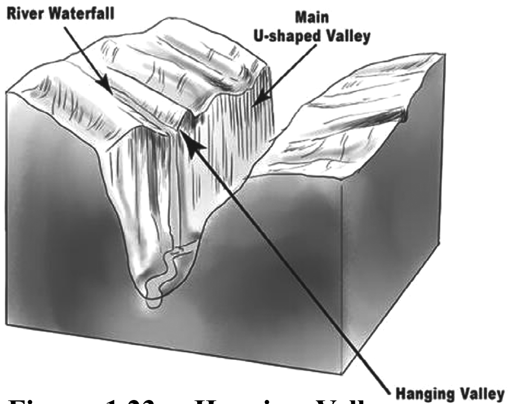


Figure 1.23 : Hanging Valley

(viii) Hanging Valley : Tributary glaciers also carve 'U' shaped troughs. But they are smaller in cross section, with floors lying high above the floor level of the main trough *i.e.*, main glacial valley.

(ix) Trans : The bed rock is not always evenly excavated under a glacier, so that floors of troughs and cirques may contain rock basin and rock steps. Cirques and upper parts of troughs thus, are occupied by small lakes called Trans.

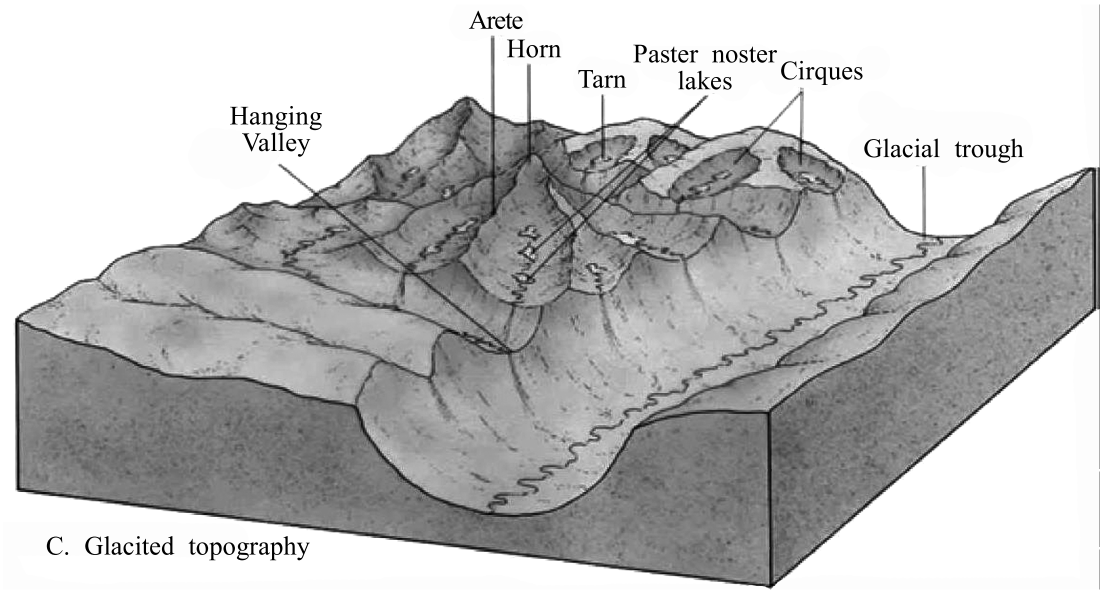


Figure 1.24 : Erosional landform by glacier movement

1.10.2 Glacial Deposition

The rock debris carried by the glaciers down the slope is known as Glacial Drift. The rock debris is deposited at the base of the glacier trough the movement of slowly moving cinemas down the slope. Landforms generally include moraines and drumlins.

Depositional Landforms of Glacial processes

These are the depositional landforms of glacial regions-

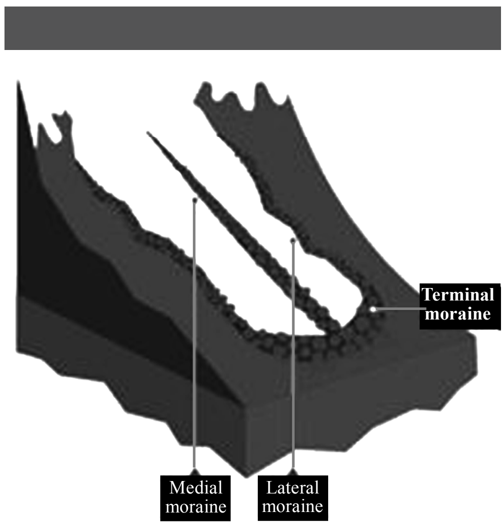


Figure 1.25 : Moraines

1. **Glacial till :** The unasserted coarse and fine debris dropped by the melting glaciers is called Glacial Till. Most of the rock fragments in till are angular to sub-angular in form.
2. **Moraines :** It consists of the heterogeneous rock materials of unsorted nature, it is a mixture of many sediments called glacier flour,

angular stones and boulders of different sizes and shapes. These materials dropped at the end of a valley glacier is in the form of ridge called the 'Terminal Moraine'. The materials deposited at either of its sides is known as 'Lateral Moraine'. When two glaciers join, their lateral moraines also join near their confluence and are called 'Medial Moraine'.

3. **Eskers :** Very coarse materials like boulders and blocks along with some minor fractions of rock debris carried into this stream settle in the valley of ice beneath the glacier and after the ice melts it can be found as a sinuous ridge called Esker.

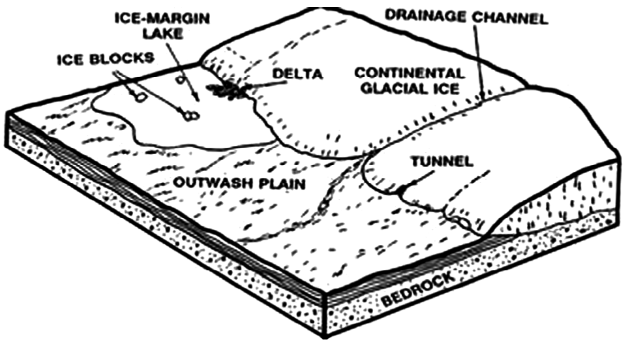


Figure 1.26 : Outwash Plain

4. **Outwash Plain :** It is also known as over wash plain. Glacial streams carry a huge quantity of rock debris and then form fan like plains beyond the terminus of glaciers. These are stratified. When, they occur on valley floors, such outwash plains are called valley trains.

5. **Erratics :** These are stray boulders of rocks which have undergone a prolonged glacial transport and have subsequently been deposited in an area, where the country rocks are of distinctly different types. At times they are delicately balanced upon glaciated bedrock and are called poking or logging-stone.

6. **Drumlins :** The drumlins form due to dumping of rock debris beneath heavily loaded ice through fissures in the glacier. The sots get blunted due to pushing by moving ice. They are smooth oval shaped ridge like features composed mainly of glacial till with some masses of gravel and sand. They may measure up to 1 km in length and 30 m or so in height.

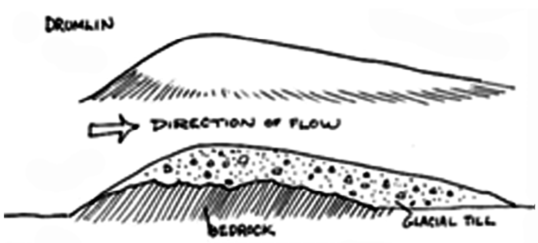


Figure 1.27 : Drumlins

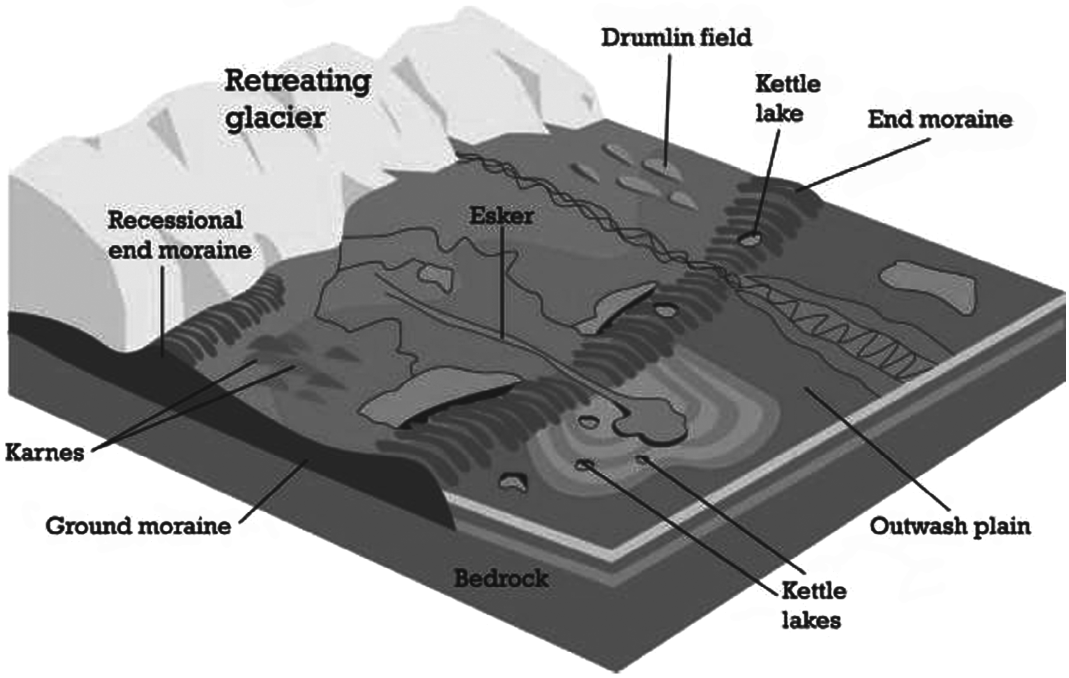


Figure 1.28 : Glacial Landforms – Depositional

1.11 Summary

There are many hypotheses on origin of earth. However. Majority of the modern scientists are of the opinion that the age of the earth may vary from 3 to 5 billion years. Through many evolutionary steps human raise appears, this has been evident in geological time scale. The internal structure is consisting of inner core, outer core, lower mantle and upper mental and finally the outer layer named as crust.

The elements of earth whose have the momentum namely wind, water and glacier, are responsible for various type of land forms. These landforms are created in erosional and depositional activity of those elements.

1.12 Questions for self-assessment

1. Discuss the internal structure of the earth with suitable diagram.
2. What is seismology? Critically examine the seismological evidence in understanding the internal structure of the earth.

3. Briefly outline the essence of plate tectonic theory and mention the origin of mountain in the light of the above-mentioned theory.
4. Describe the geological time scale. Mention its importance in geoscience.
5. Discuss the continental drift theory as proposed by A. wagner. Differentiate between plate tectonic theory and continental drift theory.
6. Give an account of three principal hypothesis put forward to explain the origin of the solar system and the earth.
7. "Since about 1943, there has been a swig back to theories of Laplacian type" Discuss this statement with reference to the theories that have been put forward regarding the origin of the solar system and earth.
8. Give a concise account of the standard geological time scale.
9. Discuss the principal characteristics of the crust, mantle and core of the earth.
10. How does seismology help in understanding the internal structure of the earth and what are its main findings?
11. Write an account of the work which a river does in the different parts of its course.
12. Give an account of either erosional or the depositional landforms produced by river action.
13. How are deltas formed? Classify deltas according to their shape.
14. Describe the processes of wind erosion under arid conditions and discuss the chief topographical features produced by them.
15. Discuss the landforms resulting from either glacial erosion or glacial deposition.
16. How does the theory of plate tectonic explain the present lay-out of the young fold mountain chains of the earth?
17. Describe the landforms produced by erosional activities of valley glacier.
18. Write a critical account of theory of continental drift as proposed by Weagner.
19. Give an account of the evolution of landform by the erosional activities of the wind.

20. Give an account of the landforms developed by the depositional action of wind in hot desert.
21. Describe and explain with sketches the geomorphic features resulting from erosion by valley glacier.

1.13 Suggested Readings

1. Harland, W. B. (1983). Geotectonics in the USSR. Geological Magazine.
2. Benioff, H. (1954). Orogenesis and deep crustal structure—additional evidence from seismology. Geological Society of America Bulletin.
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6. Strutinski, C., Stan, R., & Puste, A. (2003). Geotectonic hypotheses at the beginning of the 21st century. In Why expanding Earth? A book in honour of Ott Christoph Hilgenberg. INGV Rome.
7. Smith, A. G., & Hallam, A. (1970). The fit of the southern continents. Nature.
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Unit - 2 ❑ Rocks and Minerals

Structure

2.1 Objectives

After successfully completing this unit, you will be able to :

- know the properties and characteristics of rocks.
- visualize the formation of rocks
- demonstrate different types of igneous, sedimentary and metamorphic rocks

- understand different types of minerals
- understand different properties of minerals

2.2 Introduction

Rocks and the minerals are known to be the building blocks of our active planet. They are the reason how the landscapes are formed and these provide all the necessary valuable resources needed within our environment. Knowing about these structures, we will be able to know about the events that have shaped our earth and those which will continue to shape our planet.

You would have learnt about the phrase 'rocks and minerals' at some stage of science in schooling. The reason for which we say 'Rocks and minerals' is because that they both are two different words. Rocks are composed of minerals, but minerals are not said to be composed of rocks. The Main rocks on the earth contain minerals such as magnetite, feldspar, quartz, mica, epidote *etc*. Minerals have a commercial value which is of very immense, whereas the rocks are mined in order to extract these minerals. These mined rocks are called as ores, and the residue of these rocks after mineral has been extracted from it is called as tailing.

What is Rock?

Rocks are the materials that form the essential part of the Earth's solid crust. "Rocks are hard mass of mineral matter comprising one or more rock forming minerals". Rocks are formed from the molten material known as magma. The study of rocks is called Petrology (in Greek, petra means rock, logos means science). Petrology deals with the description of rocks; petrogenesis is the study of the origin of rocks.

2.3 Physical & Engineering Properties of Rocks

Designing structures in rocks, strength and deformation properties are extremely important. Determining the appropriate strength parameters is critical because the design must take into account the type of structure, loading characteristics, and rock characteristics in the bearing strata. Before any superstructure or heavy temporary load is allowed on the bearing strata, the important design aspects and shearing failure possibilities must be checked. Before any final design, appropriate tests to determine various rock strength properties must be planned.

Predicting performance in geotechnical engineering entails determining the properties of soil/rock and rock mass through laboratory or field tests. Laboratory tests have limitations such as sample disturbance and variability. Furthermore, testing is performed on small specimens, making extrapolation of the measured properties for the entire site difficult. In contrast, the response of a larger mass under natural insitu conditions is provided by insitu tests. They offer more affordable and timely property estimates. Poorly defined boundary conditions, non-uniform and high strain rates imposed during testing, and inability to control drainage condition are examples of limitations. Despite their limitations, both laboratory and in-situ tests are necessary components of any geotechnical design.

2.3.1 Properties of Rock

Rock materials are essentially mineral aggregates that may contain a single or multiple minerals. Rock granite, for example, is mostly composed of quarts, feldspar, and hornblende. The performance of rocks is primarily determined by their physico-mechanical properties. The physical properties (or index properties) aid in the classification of the rock. The mechanical and strength properties of the rock material provide information about its performance.

- The strength of a rock is determined by its physicochemical composition. Strength is also affected by the testing method, sample size, geometry, test procedure, loading rate, confining ‘stress, and degree of saturation.
- The physico-mechanical properties of the same rock type can vary greatly from place to place and even point to point within the same geological formation.
- In the field, stresses are mostly compressive, and it is usually attempted to reduce tensile stress accumulation.
- When unconfined, rocks are mostly brittle, but when subjected to high confining pressure, they can become ductile/plastic.

2.3.1.1 Physical Property

1. Density, unit weight, specific gravity and water content

The density of a rock is its mass per unit volume, whereas its unit weight is its weight per unit volume. Highly porous rocks with poor grain arrangement (less packing) typically have lower densities, and vice versa. The bulk unit weight takes into account the total volume of rocks, whereas the solid unit weight takes into account volume excluding pores and fissures. Obviously, for porous rocks, the solid unit weight is higher than the bulk unit weight because the value in the denominator is lower due to the exclusion of pores and micro fractures. The bulk unit weight of a rock is determined by its type, porosity, and the geological processes that occur within it.

The water content of a rock specimen can be directly calculated by dividing the mass of pore water by the mass of the sample. Saturation and buoyancy, mercury displacement, and grain specific gravity techniques are commonly used to determine porosity and density.

2. Porosity

Rocks have voids in the form of pores, joints (fissures), and so on. The voids can be linked or separated from one another. If they are interconnected and there is a pressure gradient, rock can conduct fluids or gases. Porosity is an inherent property that is defined as the volume of openings (voids) divided by the total volume of material.

The porosity of a geologic material represents its storage capacity. The primary porosity of a sediment or rock is made up of the spaces between the grains that make up that material. The lower the porosity, the tighter the grain packing. Using a box of marbles as an example, the internal dimensions of the box would represent the volume of the sample. The void space is represented by the space around each of the spherical marbles. The porosity of the box of marbles would be calculated by dividing the total void space by the total volume of the sample and expressing the result as a percentage. The primary porosity of unconsolidated sediments is determined by the shape of the grains and the range of grain sizes present.

The void index, which can be determined using the quick absorption technique, can be used to represent porosity. The mass of water contained in a rock sample after one hour of immersion, expressed as a percentage of its initial dry mass, is defined as the void index. The index is related to porosity as well as properties like degree of weathering or alteration. The test should only be used for rocks that do not disintegrate significantly when immersed in water. The void index is calculated by dividing the difference in saturated and dry weight of rock by the dry weight of rock, expressed as a percentage.

3. Electrical Properties

A material's electrical nature is defined by its conductivity (or, inversely, resistivity) and dielectric constant, as well as coefficients indicating the rates of change of these with temperature, frequency of measurement, and so on. The electrical properties of rocks with varying chemical compositions and physical properties such as porosity and fluid content can vary greatly. When a potential difference (voltage; V) across a specimen of one volt magnitude produces a current I of one ampere, the resistance (R) is one ohm; that is, V = Ri. The electrical resistivity (p) of a material is an inherent property. In other words, it is inherent and unaffected by sample size or current trajectory. R = L/A, where L is the length of the specimen, A is the cross-sectional area of the specimen, and units of are ohm-centimetres; 1 ohm-centimetre equals 0.01 ohm-metre. The conductivity (sigma) is defined as 1/ohm^{-1} centimetre^{-1} (or mhos/cm). It is expressed in SI units as mhos/ metre or siemens/metre.

Materials with a resistivity of 10-5-10 ohm-centimetre (10-7-10-1 ohm-metre) and a conductivity of 10-107 mhos/metre are considered "good" conductors. The resistivity of intermediate conductors is 100-109 ohm-centimetre (1-107 ohm-metre) and the conductivity is 10-7-1 mhos/metre. The resistivity of "poor" conductors, also known as insulators, is 1010-1017 ohm-centimetre (108-1015 ohm-metre) and the conductivity is 10-15-10-8. Because of its higher concentration of dissolved salts, seawater is a much better conductor (has lower resistivity) than fresh water; dry rock is very resistive. Fluids typically fill pores in the subsurface to some extent. Materials have a wide range of resistivity—copper is an example.

4. Magnetic Properties

The magnetic properties of rocks are derived from the magnetic properties of the constituent mineral grains and crystals. Magnetic minerals are typically found in only a small percentage of rock. This small portion of grains determines the magnetic properties and magnetization of the entire rock, resulting in two outcomes: (1) The magnetic properties of a given rock may vary greatly within a given rock body or structure, depending on chemical inhomogeneities, depositional or crystallisation conditions, and what happens to the rock after formation; and (2) rocks with the same lithology (type and name) do not necessarily share the same magnetic properties. Lithologic classifications are typically based on the abundance of dominant silicate minerals, but major rock-forming magnetic minerals are iron oxides and sulfides.

5. Thermal Properties

Thermal conductivity is an important thermophysical rock property that is required for determining heat flow, determining deep thermal regimes, and reconstructing the thermal history of a sedimentary basin. The thermal conductivity of rocks is generally accepted to decrease with increasing temperature and increase with increasing pressure, and the effects of temperature and pressure cancel each other out. Although many measurements of thermal conductivity of igneous and metamorphic rocks have been taken, sedimentary rocks and heat flow in sedimentary basins have received little attention. Samples for the investigation were collected from boreholes (from a deep formation, approximately 3000 m) and outcrops representing sedimentary rocks with an aleuritic structure. Under inert and oxidising conditions, the mineral composition was determined using TG/DSC analysis. Thermal conductivity of the examined rocks ranges from 0.96 to 6.06 W m^{-1} K^{-1} and is strongly dependent on mineral content and bedding direction.

6. Mineral Composition

Minerals make up the majority of rocks. Geologists define minerals as naturally occurring inorganic solids with a crystalline structure and a distinct chemical composition. Of course, the minerals found in Earth's rocks are produced by a variety of different chemical element arrangements. A list of the eight most common elements making up the minerals found in the Earth's rocks is described in table.

Element	Chemical Symbol	% In the earth crust
Oxygen	O	46.60
Silicon	Si	27.72
Aluminium	Al	8.13
Iron	Fe	5.00
Calcium	Ca	3.63
Sodium	Na	2.83
Potassium	K	2.59
Magnesium	Mg	2.09

2.3.1.2 Engineering Properties

1. Elastic constants

There are several constants in elastic deformation that relate the magnitude of the strain response to the applied stress. These elastic constants are as follows:

Young Modulus : Young's modulus (E) is defined as the ratio of applied stress to fractional extension (or shortening) of sample length parallel to tension (or compression). The strain is calculated by dividing the linear change in dimension by the original length.

Share Modulus : Shear modulus is the ratio of applied stress to distortion (rotation) of a plane that was initially perpendicular to the applied shear stress; it is also known as the modulus of rigidity.

Bulk Modulus : The bulk modulus is the ratio of confining pressure to fractional volume reduction in response to applied hydrostatic pressure. The volume strain is defined as the sample's change in volume divided by its original volume. The modulus of incompressibility is another name for the bulk modulus.

2. Stress & Strain

When a material, like rock, is subjected to stress (force per unit area), the material changes in size, volume, or shape. Strain is the name for this transformation or deformation. Stresses can be axial, such as simple compression or directed tension, or shear (tangential), or they can be all-sided (e.g., hydrostatic compression). Although the terms stress and pressure are frequently used interchangeably, pressure (P) generally refers to hydrostatic compression and stress usually refers to directional stress or shear stress. The strain is elastic under mild forces (recoverable when the stress is removed and linearly proportional to the applied stress). The strain may be inelastic, or permanent, with higher stresses and under other circumstances.

2.4 Formation of rocks

1. Cooling and consolidation of molten magma within or on the surface of earth = **Igneous** or **Primary rocks**
2. Transportation and cementation of primary rocks = **Sedimentary or Secondary rocks**
3. Alteration of the existing primary and secondary rocks = **Metamorphic rocks**

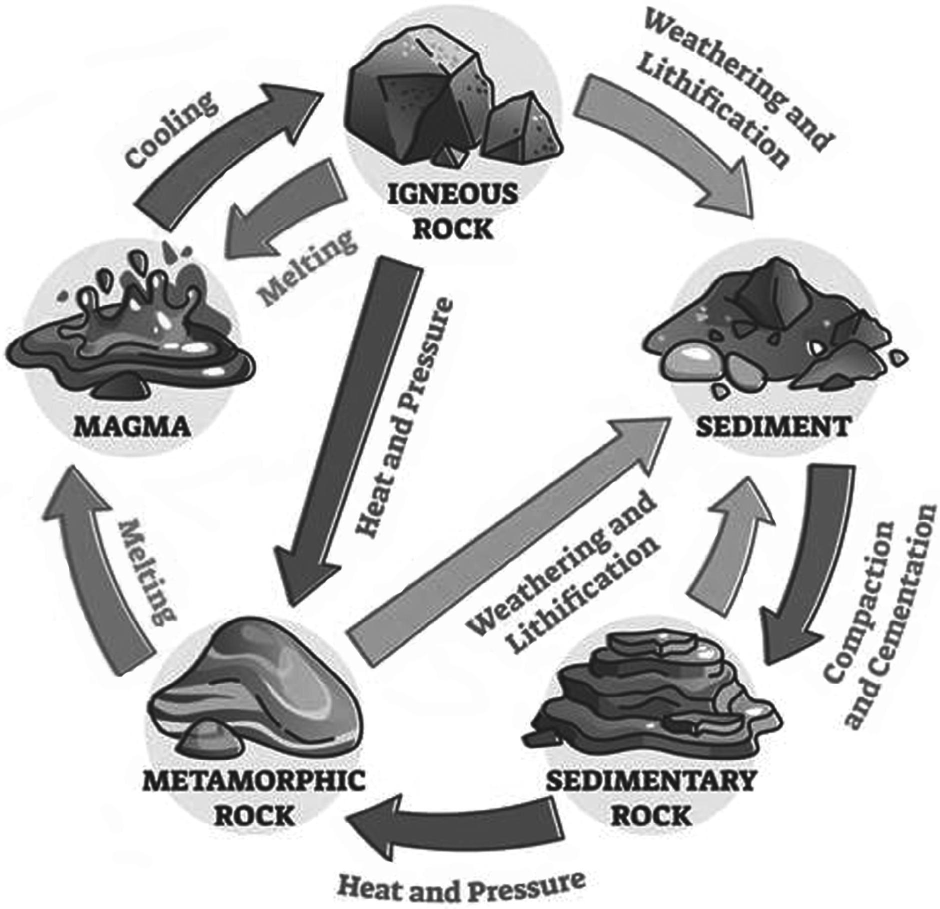
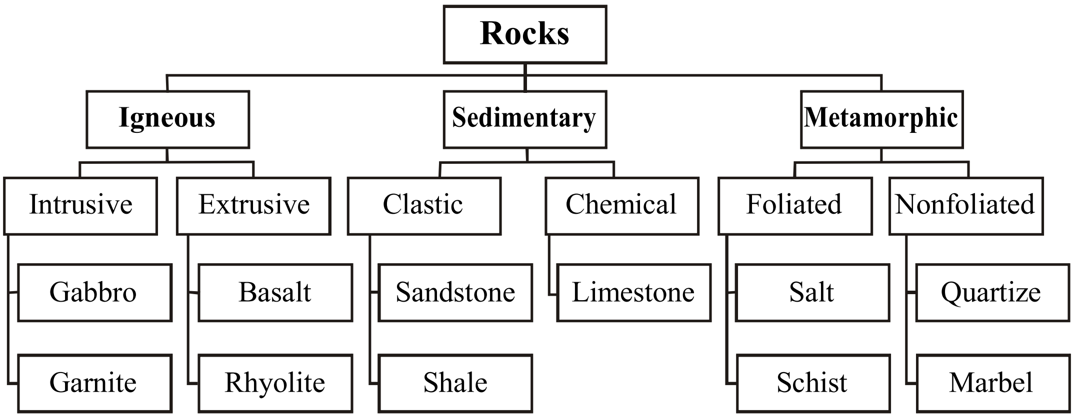


Figure 2.1 : Rock formation

2.5 Types of rocks

Rocks are classified in to three types according to their formation. Which are

1. Igneous rock
2. Sedimentary rock
3. Metamorphic rock



2.6 Igneous rocks (primary or massive rocks)

Figure 2.2 : Igneous rock

Igneous rocks are formed as magma (molten rock) cools and solidifies. Magma is produced far below the Earth's surface by heat generated mainly from radioactive disintegration of uranium, thorium and potassium. The two main types of igneous rock are extrusive and intrusive.

2.6.1 Characteristics of Igneous Rocks

Magmetic Consolidation : Ordinary layers are not present in the igneous rocks. The deposition of erupted lave at various points in time results in the formation of the layers of igneous rocks. In reality, these layers are time intervals between a series of magmatic eruptions.

Both Crystalline and Non-Crystalline : Both crystalline and non-crystalline igneous rocks exists. If the magma that forms in fissures cools quickly, it does not have time to crystallise and becomes non-crystalline like basalt. The magma slowly cools and crystallises when it does not come to the surface of the Earth but instead cools in the various empty spaces beneath it. Granite-like crystals would be larger if the rate of cooling lower. However, the crystals lack a set order or shape and are formed according to regional circumstances.

Non-porous : For water, these rocks have no pores. They prevent water from soaking through.

Content of Silica : These have 40 to 80 percent silica content. Magnesium and iron are important, among other things.

Absence of Fossil : There are no fossils in these rocks.

2.6.2 Classification of Igneous Rocks

Extrusive rocks or volcanic rocks

These rocks are formed due to the consolidation of magma on the surface of the earth. The magma, when it flows on the Earth surface is called LAVA. *E.g.*, Basalt.

Intrusive rocks or plutonic rocks

These rocks are produced due to solidification of magma below the surface of the earth. Plutonic – intrusive rocks solidify at greater depth and Hypabassal rocks solidifies at shallow depth from the surface. *e.g.*, Granite, syenite, diorite, Gabbro *etc*. Rocks formed in vertical cracks are called dykes and in horizontal cracks are called sills.

Vesicular rocks :

Molten magma cools on the surface. Steam of water is entrapped into rocks and forms vesicles.

A. Based on the silica content, rocks are also classified as

1. Acid rocks : > 65% SiO_2 (Granite, Rhyolite)

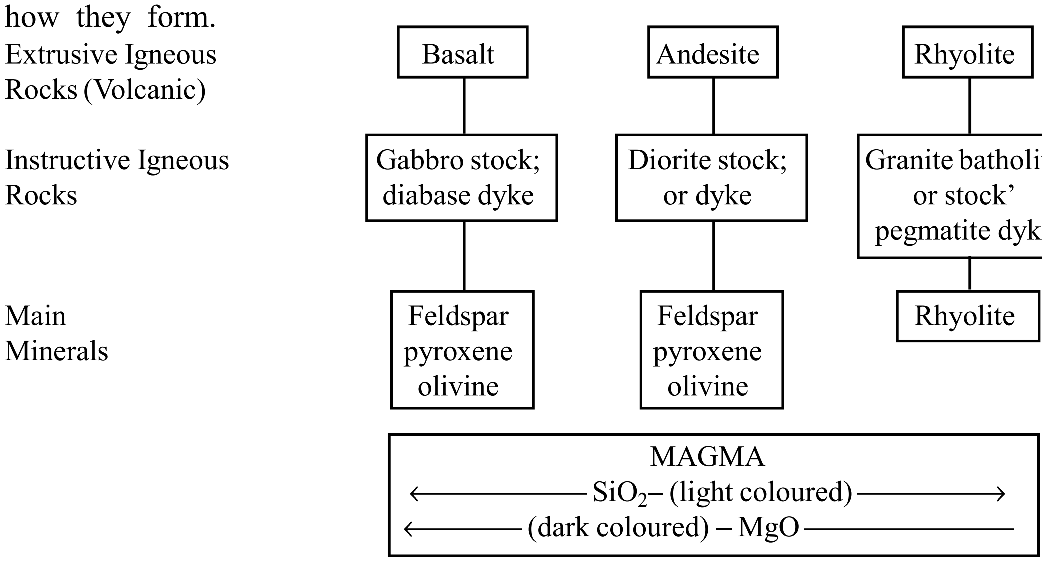
2. Intermediate : 56 to 65% SiO_2

(Sub acid rocks 60 to 65% SiO_2 (Syenite and Trachyte))

(Sub basic rocks 56 to 60 % SiO_2 (Diorite and Andesite))

3. Basic rocks : 40 to 55% (Gabbro, basalt)

The table below shows the relationship between different igneous rocks and how they form.



B. Classification on the basis of form :

(i) Laccolith : From the Greek word "locos," which means "cistern," comes the word "laccolith". It is an illustration of a coherent igneous body. Diorite, granite, and other magmas with a higher silica content harden at room temperature. The magma does not percolate deeply into layers in such a situation. The solidified magma rises like a dome when the amount of molten magam below it increases. This dome typically has a flat base and a round or oval shape. Its surrounding layers are also warped upward. Such domes have many kilometres in diameter and thousands of metres in thickness. Examples include the Henry Mountains, the Lal Sal Mountain in Utah, others. Some laccoliths have the shape of a cedar tree.

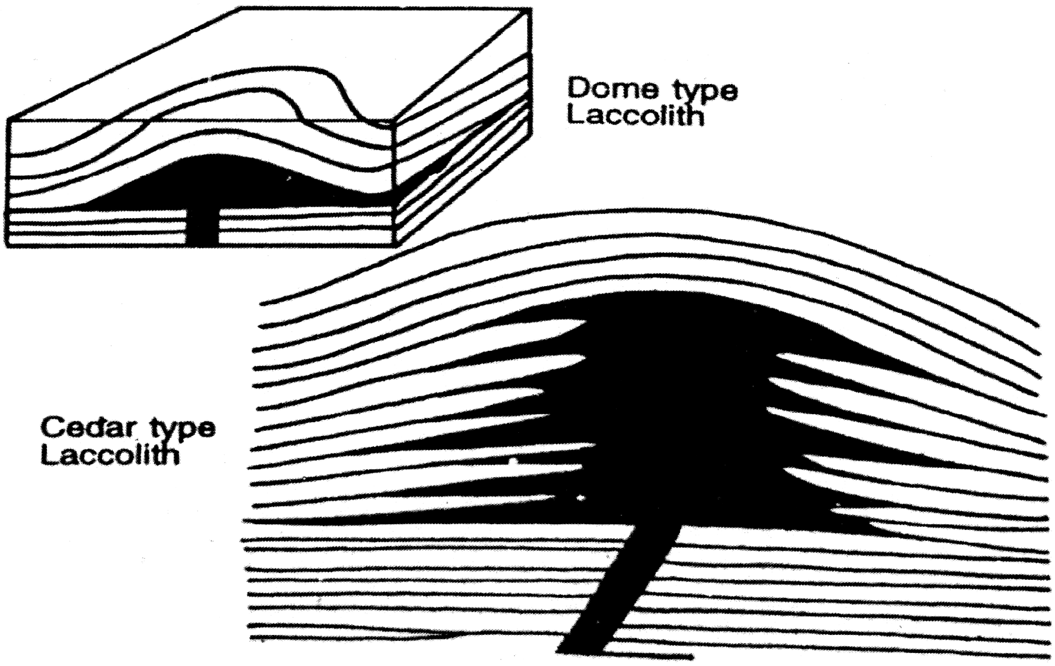


Figure 2.2A

(ii) Batholith : Batholiths are formed when molten magma gather over a large area in a pattern that cuts through multiple layers. The buildup extends both upwards and downwards. It is intense and lacks a bottom that can be seen. The upper layers of the parts have cracks in them where the molten material enters. It is referred to as stock if the exposed portion of the upper part in less than 100 sq. km. The stocks are cylindrical structures that are found in the Earth's lower layers. The magma frequently rises through them and emerges on the surface.

(iii) Lopolith : Lopoliths are created when batholiths are deposited into a concave shape.The word "lopas," which means "bowl, flat saucer, or basin," is Greek. South Africa has a large number of lopoliths, including the Bushweld lopolith in the Transvaal region of that country.

(iv) Sill : Magma that is hot and molten and is erupting from the interior of the Earth passes through weaker areas and cools off around them. It is referred to as a sheet when it cools down parallel to the surface in a thin layer. Sill is the term used to describe a thick sheet. In North England, a whin sill that is 27.4 metres high and 128 kilometres long. In North America, Palisade Sill is located on the Hudson river's western bank. It sands at about 274 metres.

(v) Dyke : When the megma after cooling is not parallel to the layers around it and makes an angle with them, it is called **Boss**. If its angle is 90°, it is called Dike (Dyke American spelling). There are many dikes in the Spanish Peak of Colorado. Columbian Plateau, etc. There are many dikes along a distance of 160 km, in Northern England. The largest dike known is the dike of Zimbabwe (Africa) which is about 600 km long about 10 km wide.

There are many types of dykes such as Radial Dykes. Ring Dykes Dyke Swarms. Dilaton Dykes, etc.

Radial Dykes—When pressure exerted by the magma radial fissures in an area under tension, the magma rushes in and fills radial fissures and form radial dykes.

Ring Dykes—When the cyclindrical section of the crust gets an invasion of magma at the circular or elliptical masses of rock, it gets solidified and is know as Ring Dykes.

Dyke Swarms—When formed in the form of radial pattern or get paralled to each other around igneous intrusion are called Dyke Swarms. These are usually found in Greenland and lceland.

Table 2.1 : Details of some igneous rocks

S. No.	Rocks	Origin	Essential minerals	Common minerals	Average specific gravity	Remarks
1.	Granite	Plutonic holocrystalline	Quartz (20-30%)	Hornblende, magnetite, mica	2.64	Light coloured white or reddish
2.	Syenite	Plutonic holocrystalline	Quartz, orthoclase	Hornblende, magnetite, biotite	2.80	Light coloured white or reddish
3.	Diorite	Plutonic holocrystalline	Quartz	Hornblende, magnetite, biotite	2.85	Darker
4.	Gabbro	Plutonic holocrystalline	Labradorite, augite, olivine	Hornblende, ilmenite	3.0	Blackish
5.	Dolerite	Hypabasal	Labradorite, augite, olivine	Hornblende, ilmenite	3.0	Blackish
6.	Basalt	Volcanic crystalline with glassy mass	Labradorite, augite, olivine	Hornblende, ilmenite	3.0	

2.7 Sedimentary rocks

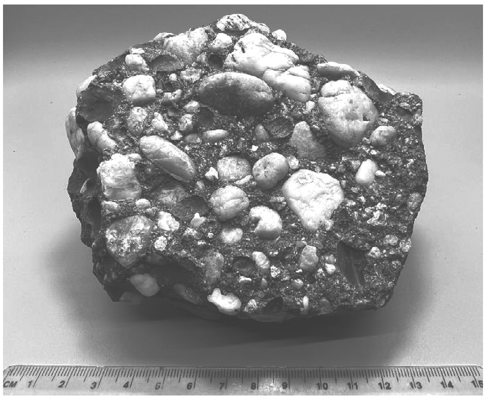
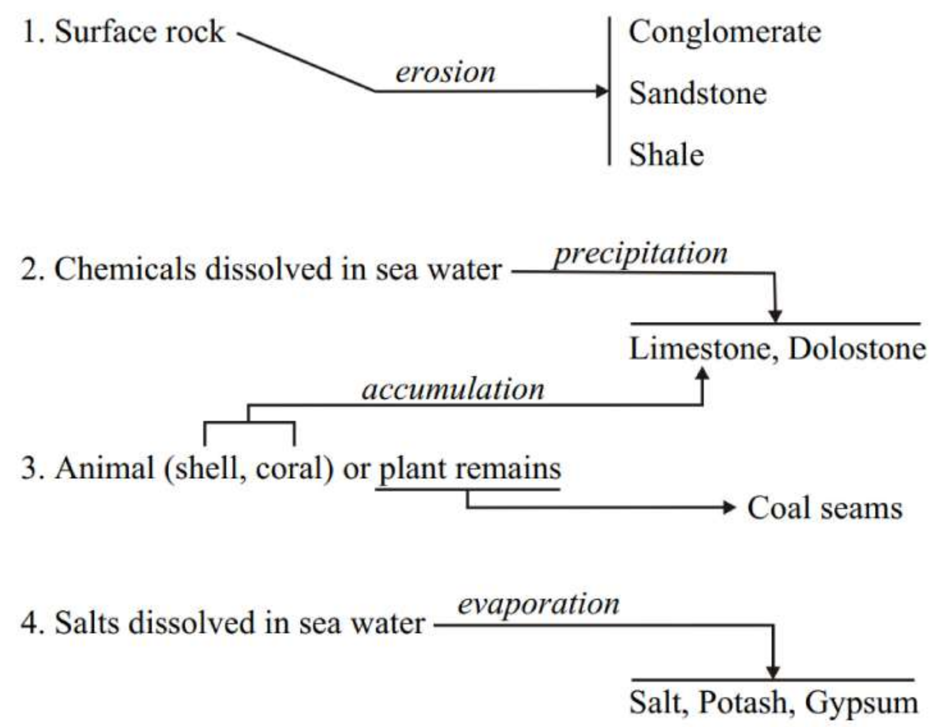


Figure 2.3 : Sedimentary rock

These rocks are formed from the consolidation of sediments accumulated through wind or water action at the surface of the earth. Many are deposited in layer or formed through chemical reactions as precipitates from aqueous solutions. Sediments may contain various size particles cemented together by substances like SiO_2, Fe_2O_3 or lime. These rocks are also called as clastic rocks.

Sedimentary rocks may have a coarse-grained, gravel-like appearance or be extremely fine grained, and may be hard or soft. The principal varieties are sandstone, limestone and shale. Many sedimentary rocks contain fossils and some, such as coral reefs, are composed entirely of such organic remains. The figure below illustrates how sedimentary rocks form



2.7.1 Characteristics of Sedimentary Rocks :

Stratification—These rocks display many layers in them. On account of the existence of many layers in them, they are called stratification rocks.

Fossilisation—The rocks have fossils of plants and animals in them. The fossils help the dating of the age of the rocks and throw light on evoluation of plant and animal life.

Porosity—The fact that the rocks are made up of fine, small, and large particles makes them porous. Through the pores between the particles, the water percolates.

Marks and Imprints : Sand make up the majority of the sediment at the shallow seashore. Ripple Marks are frequently used to identify it when being attacked by sea waves. These crest and trough imprints of waves are visible and simple to locate. In the direction of the oncoming waves, long slopes form. The floods create enormous wave traces. These waves have 0.5 to 1 metre high crests and troughts that are spaced 70 to 110 means apart.

The remaining water from the coast flows back as small rills after the floods have subsided. Such rills can be seen in the consolidated sediments, which occasionally resemble fossils. They are referred to as Rill Marks. On coastal sand, waves leave a significant amount of their imprint. They are referred to as Wave marks. Old sedimentary deposits rerely contain these impressions. A new sedimentary layer is immediately formed over the sediments that are marked by raindrops that land on relatively hard and dry sedimentary ares. On the sediment, they leave their mark. The raindrop marks live longer if a new sedimentary layer is immediately formed over them because they are protected from deterioration. Sun exposure causes cracks in the rocks.

Erosion : Compared to other types of rocks, sedimentary rocks erode and weather more quickly.

2.7.2 Types of sedimentary rocks

Based on the origin, the sedimentary rocks are classified as

1. Residual : Laterite
2. Transported
   a. Deposited as solids in suspension : Sandstone, shale
   b. Deposited by chemical precipitation : Limestone, ironstone
   c. Deposited through agency of organic matter : Peat, Phosphatic deposits

Based on the grain size, sedimentary rocks are classified as

1. Rocks with boulder pebbles sized minerals (Rudaceous) : Conglomerate
2. Rocks with sand size particles (Arenaceous) : Sandstone
3. Rocks with silt size particles (silt rocks) : Siltstone
4. Rocks with clay size particles (Argillaceous) : Shale

Table 2.2 : Details of some sedimentary rocks

S. No.	Rock	Mineral composition	Colour and structure
1.	Sandstone	Mainly quartz with some $CaCO_3$, iron oxides and clay	Light to red, granular
2.	Shale	Clay minerals, quartz and some organic matter	Light to dark thinly laminated
3.	Limestone	Mainly calcite with some dolomite, iron oxides, clay, phosphate and organic matter	Light grey to yellow, fine grained and compact

2.7.2 Sedimentary rocks divided into six groups as follows

1. **Arenaceous :** Formed of the deposits of coarse-grained particles. They are composed of siliceous material derived from the disintegration of older rocks. The fragmental material so derived is deposited in beds of varying thickness through the agency of water. Depending upon the nature of cementing material present, some arenaceous rocks are hard and refractory, but most are loose and fall away very easily. *e.g.*, Sandstone, grit, conglomerate and breccia.

2. **Argillaceous rocks :** Consist of small sized particles known as clay. They are composed of hydrated silica of alumina in admixture with sand, various other silicates and calcareous matter. When clay is deposited mainly of silicate of alumina, it is known as kaolin or China clay. *e.g.*, clay, mudstone, shale and fuller's earth.

3. **Calcareous rocks :** Consists of carbonate of lime or lime and magnesia. They may be of sedimentary origin or formed by chemical precipitation or by organic agency. When, they are of organic agency, they are composed mainly of debris from plant and animal life. They are formed either by growth and decay of organisms in situ or by the transport and subsequent accumulation of their remains. The rocks so formed are found in layers, which vary considerably in depth of thickness.

   When formed by chemical precipitation, the calcareous material is deposited in the form of layers/sheets from waters containing calcium carbonate in solution. The precipitate when first formed is usually soft and chalky, but soon acquires a hard, compact structure and crystalline texture. The important calcareous rocks of aqueous origin are limestone, chalk, magnesian, ferruginous limestones, dolomite, marks of various varieties and coral.

4. **Carbonaceous rocks :** Formed from decomposing vegetation under anaerobic conditions. When plants undergo decomposition under restricted air supply, is greater portion of the carbonaceous matter is retained and the material is slowly converted into coal. *e.g.*, peat, lignite, coal, anthracite.

5. **Siliceous rocks :** Siliceous rocks of organic origin formed from parts of minute plants and animals like diatoms, radiolaria *etc*, some are soft and friable and crumble to powder very easily. Others like flint and chert are hard and compact.

6. **Precipitated salts :** Consist mainly of deposits formed as rock masses either by cooling, evaporation or by chemical precipitation. Water charged with acid or alkaline material, acting under pressure as it does under subterranean regions, dissolves various mineral substances from rocks with which it comes in contact. The salts thus formed deposit as rocks and such rocks vary in composition. They are

   (i) Oxides : *e.g.*, hematite, limonite, bauxite and quartz.

   (ii) Carbonates : *e.g.*, stalactite, stalagmite, magnetite and limestone.

   (iii) Sulphates : *e.g.*, gypsum and anhydrite

   (iv) Phosphates : *e.g.*, phosphorite

   (v) Chlorides : *e.g.*, rock salt.

2.8 Metamorphic rocks

Metamorphic rocks are formed when rocks of any class are subjected to heat and pressure at depth. This causes new minerals to form and other minerals to recrystallize. During the process, material from the rock may be added or lost. Marked changes in temperature (T) and pressure (P) occur, which may produce completely new types of rocks. In addition to the formation of new minerals, existing minerals may be realigned into parallel bands and new textures may be formed. At sufficiently high temperatures, the rock may undergo partial melting to form m agma, which may then become the source of an igneous rock. Metamorphic rocks include, gneiss, schist, slate, quartzite and marble, and the below figure shows how they form.

2.8.1 Causes of Metamorphism

1. **Orogenic (Mountain building) movements :** Sometimes these movements exert so much pressure on the rocks that they are warped and compressed. Sometimes the rocks are melted and then again get solidfied. This process gives them new appearance. For example, shale is converted into slate. Similarly, sandstone is converted into Quartzite.
2. **Lava inflow :** The lava coming out of volcanoes sometimes occupies vacant spaces between rocks. The high pressure and high temperature caused by lava inflow produces metamorphism in the surrounding rocks.
3. **Geodynamic Forces :** The geodynamical forces are always at work and continue making changes in the layers. Many rocks subjected to pressure and temperature are metamorphosed.
4. **Action of Underground Water :** The underground water dissolves some rock particles and transports them to other places where the dissolved particles are deposited. Due to chemical action between the dissolved chemical substances and their crystallisation, new rocks are formed and are known as **metamorphic rocks.**
5. **Mineralisers :** Liquids and vapours given off from magnetic material are usually at high temperature. These hot liquids and vapours penetrate into rocks and produce metamorphism. Such hot liquids and vapours are called **mineralisers.** The usual mineralisers are Steam, Chlorine, Fluorine and Boric acid.

2.8.2 Types of Metamorphism

Metamorphism is classified on the bases of agency that brings about metamorphism and on the Zones of Influence where it is caused.

(I) On the basis of Agency : Metamorphism is caused by thermal and dynamic agencies.

(a) **Thermal Metamorphism :** If metamorphism is brought about by heat, it is called Thermal Metamorphism. Heat is received through many ways in this metamorphism. (i) **Hot magma-**It raises high temperature, (ii) **Mutual Friction-**The rocks when subjected to movement produce heat by mutual friction, (iii) **Hot gases, vapours and liquids-**It has already been mentioned that hot mineralisers (Chlorine, vapours, etc.) produce metamorphism. The extent of metamorphism will however depend upon the nature and amount of mineralisers, the pressure exerted and the porosity of rocks, (iv) **Geothermal heat**– Earth's heat alone is capable of bringing about metamorphism. This happens in rocks below the surface of the Earth where the temperature is high. This is not due to the high temperature of magma. For example, clay has changed into shale in the geosynclines of the Alps.

(b) Dynamic Metamorphism : The rocks of the earth are subjected to pressure due to geodynamic forces. Rocks are warped and their temperature rises. If water is available, the minerals are reorganised into new compounds Mylonite is a mineral which is metamorphosed in this way.

(II) On the bases of zones of influence : On this basis the metamorphism is of two type:-

(a) Contact Metamorphism : The magma emitted out of fissures lows into empty spaces in the rocks. When the empty spaces filled with magma, the temperature and pressure of rocks increase. The maximum metamorphism takes place at the contact zones and metamorphism decreases as we move away from the contact zones, batholith produces most of the metamorphism. There are many examples of contact metamorphism in the Deccan of India and Granite area of North America.

(b) Regional Metamorphism : The sedimentary strata are crumpled, crushed and folded due to pressure developed in geosynclines. This is mainly due to pressure and not temperature but effect of temperature is also found to work on the rocks in the interior. Example of regional metamorphism is found in the Alps, the Himalayas, the Rocky, etc.

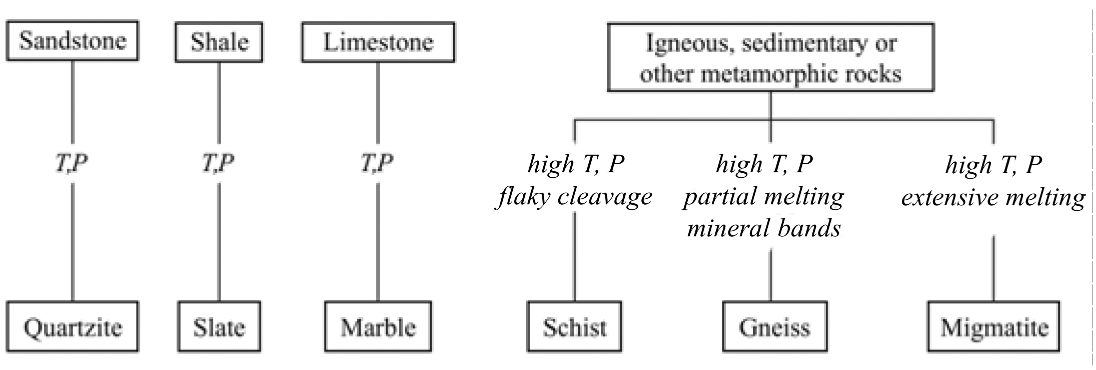


Figure 2.4 : Metamorphic rock [Gneiss]

Table 2.3 : Details of some metamorphic rocks

S. No.	Rock	Mineral composition	Colour and structure
1.	Gneiss	Formed from granite	Alternating light and dark colours, banded and foliated
2.	Schist	Formed from basalt or shale	As original rock, foliated
3.	Quartzite	Formed from sandstone	Light or brown, compact and uniform texture, foliated structure
4.	Slate	Formed from shale	Grey to black, compact and uniform texture, foliated structure
5.	Marble	Formed from lime stone	Light red, green, black, compact fine to coarse texture, foliated structure

2.9 Minerals

Minerals are naturally occurring solids with a definite chemical composition and crystal structure. "Solid substances composed of atoms having an orderly and regular arrangement".

When molten magma solidifies, different elements present in them freely arrange in accordance with the attractive forces and geometric form. Silica tetrahedron is the fundamental building blocks for the formation of different minerals. (SiO_2). Different silicate minerals are ortho silicates, ino-silicates, phyllosilicates and tectosilicates. There are nonsilicate minerals also. These are different oxides, carbonates, sulphates, phosphates *etc*.

Minerals that are original components of rocks are called primary minerals. (feldspar, mica, *etc*.). Minerals that are formed from changes in primary minerals and rocks are called secondary minerals (clay minerals). Those minerals that are chief constituents of rocks are called as essential minerals (Feldspars, pyroxenes micas *etc*) and those which are present in small quantities, whose presence or absence will not alter the properties of rocks are called accessory minerals (tourmaline, magnetite *etc*).

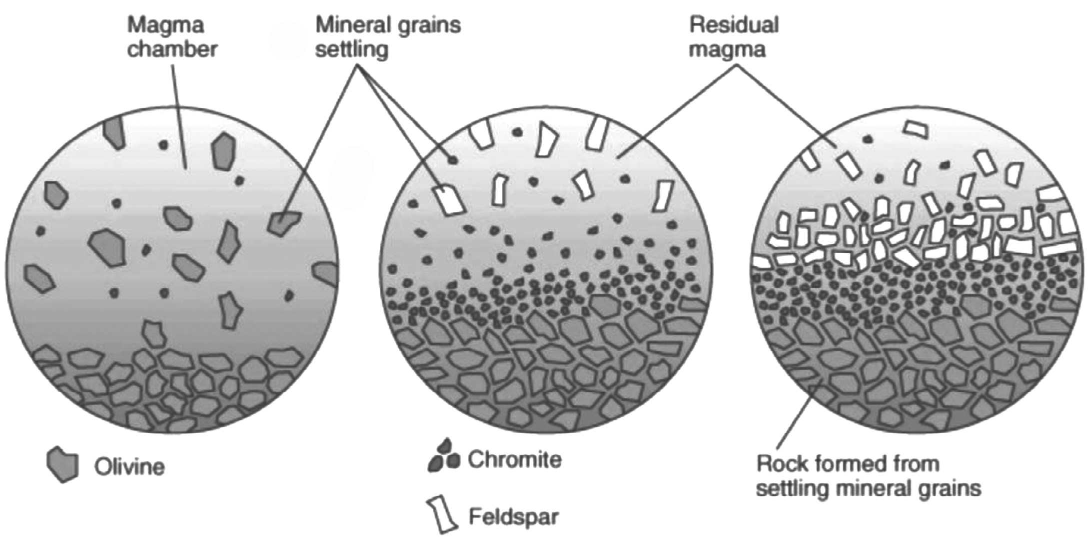


Figure 2.5 : Mineral

2.9.1 Types of minerals

2.9.1.1 Ferromagnesium minerals

(a) **Pyroxenes and amphiboles :** The pyroxenes and amphiboles are two groups of ferromagnesian minerals (heavy group) the structure of which consists of long chains of linked silica tetrahedral. The pyroxenes consist of a single chain (2 oxygen shared in each tetrahedron) whereas amphiboles consist of a double chain (alternately 2 and 3 oxygen atoms shared successive tetrahedral). These chain silicates are sometimes referred to inosilicates. The pyroxene group of minerals comprised of different minerals namely enstatite, hypersthene, diopside and augite, of which augite is the most important minerals in soils and it is found in basic rocks. The amphibole group of minerals are common in acidic rocks and it can be represented by the isomorphous series between tremolite actinolite olivine and hornblende. Hornblende weathers fairly rapidly. Olivine (olive-green) minerals from an isomorphous series between foresterite (Mg_2 SiO_4) and fayalite (Fe_2SiO_4). Pyroxenes are more basic in character and therefore it weathers more rapidly than amphiboles.

(b) Mica : Micas occur extensively in soils. They are primarily originated from the parent rock from which the soil is derived. Generally, soils are inherited from well-ordered and imperfectly ordered micas. Well-ordered micas are derived from sedimentary rocks. The most common well-ordered micas are muscovite, paragonite, biotite and phlogopite (trioctahedral). The imperfectly ordered micas contain less potassium and more water as compared to well-ordered micas and this type of micas are most abundant in the clay fraction of soils. Among the ordered micas, biotite weathers more rapidly than muscovite. In imperfectly ordered micas, many of the illite-type specimens as well as the disordered micas of soils exhibits some mixed-layering with phases of vermiculite, smectite group of minerals, chlorite and intergrades of several of these species.

2.9.1.2 Non-ferromagnesium minerals

(i) Feldspars : Feldspars are anhydrous aluminosilicates of K, Na and Ca and occasionally of other large cations such as Ba. The feldspar structure consists of tetrahedral which are attracted by sharing each oxygen atom between neighbouring tetrahedran. The tetrahedral contain mainly Silicons with sufficient Al substitution. It belongs to the group of minerals that are light in weight. There are two groups of feldspars :

(i) potassium feldspars ($KA1Si_3O_8$) include orthoclase, microcline, adularia and sanidine. Orthoclase and microcline are more common in the plutonic and metamorphic rocks. The potassium feldspars occur commonly in the silts and sands of soils and also abundant in clay-size,

(ii) plagioclase feldspars-a series consisting of a solid solution of albite ($NaA1Si_3O_8$) high in sodium and anorthite ($CaA1_2Si_2O_8$) high in calcium. Plagioclase weathers more rapidly than orthoclase.

(ii) Quartz : It is very densely packed and occurs in a high degree of purity. It is strongly resistant to weathering as the structure is densely packed, electrically neutral and free from any substitution. It is the most abundant mineral next to feldspars. Serpentine, a hydrous magnesium silicate occurs more commonly as a secondary product. Garnets are characteristic of metamorphic rocks and are very hard and most resistant to weathering.

2.9.1.3 Silicate minerals

(a) Ortho / Neosilicates

The minerals in this group are composed of single tetrahedral linked together by Mg or Fe. To effect a break down, it is considered sufficient to sever the weaker Mg-O or Fe-O bonds. Non-withstanding the bond energy considerations susceptibility of the minerals in this group to breakdown by weathering appears to vary considerably from one mineral to another, *e.g.*, zircon makes the mineral comparatively hard. On the other hand, the looser packing of oxygens in olivine makes the mineral weather faster.

(b) Inosilicates

The inosilicate group has in its structure single-chain (pyroxenes) and double chain (amphiboles) silica tetrahedral linked together by Ca, Mg, or Fe. Because of the presence of many weak spots provided by the Ca-O, Mg-O, or Fe-O bonds, these minerals tend to weather rapidly

(c) Phyllosilicates

Linkages of silica tetrahedral and Alumina octahedral sheets by mutually shared oxygen atoms from the basis for the structure of this group. Some of the minerals, *e.g.*, biotite and muscovite, are relatively susceptible to weathering, whereas others, like clay minerals, are resistant weathering products and further breakdown of clays is difficult. Disruption of interlayer ions, or through cleavage of A1-O bonds in tetrahedral and octahedral positions.

(d) Tectosilicates

The minerals are considered solid solution minerals with a framework of silica tetrahedral, in which the cavities are occupied by Na, Ca, and so on. The minerals in this group may also vary considerably in their resistance to weathering, *e.g.*, leucite and plagioclase versus potash fertilizers. The relative degree of close packing of atoms in their structural frame work may be the reason for such variability in weathering. Increased substitution of A1 and Si in tetrahedral of plagioclase mineral is also considered a factor that makes these minerals weaker than potash feldspars.

2.9.1.4 Non-silicate minerals

Oxides : Hematite (Fe_2O_3)

Limonite (Fe_2O_3, $3H_2O$)

Goethite (FeO (OH) H_2O)

Gibbsite ($Al_2O_3H_2O$)

The red, yellow or brown colours in soils are due to the presence of goethite and hematite, which occur as coatings on the surface of soil particles.

Carbonates : Calcite ($CaCO_3$)

Dolomite ($CaMgCO_3$)

Sulphates : Gypsum ($CaSO_4.2H_2O$)

Phosphates : Apatite (Rock phosphate Ca_3 $(PO_4)_2$ - primary source of phosphorus

2.9.2 Physical properties of minerals

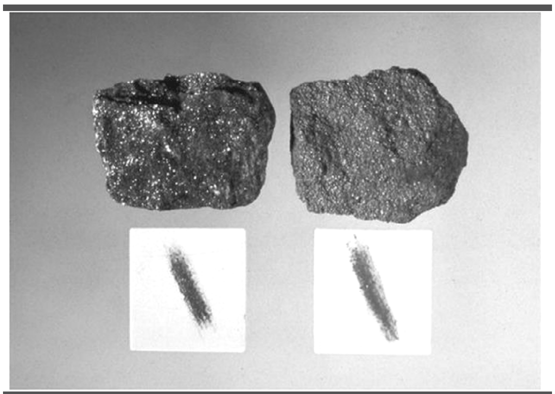
1. Color
2. Streak
3. Fracture / cleavage
4. Hardness
5. Luster
6. Crystal form
7. Taste
8. Specific gravity
9. Magnetism
10. Effervescence (fizz)

11. Birefringence
12. Fluorescence

(a) Color

- Denotes the natural colour of the mineral
- The most obvious, but least reliable.
- Calcite has more colours
- Sulfur and Pyrite have same colour

Figure 2.6 : Colour



(b) Streak

- Refers to the colour of the powder form of the mineral, when an unknown mineral is rubbed against a piece of unglazed porcelain (streak plate) it produces a colored line.
  - ➢ Hematite - red
  - ➢ Magnetite - Black
  - ➢ Talc - white

(c) Fracture and Cleavage

These terms describe the way a mineral breaks Fracture is the nature of the surface produced as a result of its breakage

Conchoidal	-	curved surface
Uneven	-	Uneven surface
Hackly	-	Jagged surface
Earthy	-	Like chalk
Even	-	Smooth

(d) Cleavage

Some minerals break along certain well-defined planes called cleavage planes.

Gypsum	-	1 set
Calcite	-	2 sets
Flourite	-	3 sets

(e) Hardness

This is how resistant a mineral is to being scratched. We use the Mohs scale to classify a given minerals hardness. Try to scratch the unknown mineral with various items, such as a fingernail (hardness of about 2.5), a coin (3), a steel nail (5.5) and a steel file (7)

Table 2.4 : Mohs Scale of Hardness

Mineral	Hardness	Mineral	Hardness
Talc	1	Feldspar	6
Gypsum	2	Quartz	7
Calcite	3	Topaz	8
Fluorite	4	Corundum	9
Apatite	5	Diamond	10

(f) Luster

The way a mineral reflects light Metallic (Magnetite); sub-metallic, Vitreous (Opal), Resinous (Pyrite), Pearly, Adamentine (Diamond), silky (Asbestos) and greasy.

(g) Crystal form

Crystal structure is the result of regular grouping of atoms that are homogeneous. A crystal is a polyhedral form, which means it is a geometric solid. It has a specific set of faces, corners and edges, which is consistent with the geometric packing of the atoms

There are 6 basic crystal forms

1. Isometric
2. Tetragonal
3. Hexagonal
4. Orthorhombic
5. Monoclinic
6. Triclinic

(h) Taste

This property is used to identify the mineral halite (salt)

(i) Specific Gravity

This characteristic relates to the mineral's density. If the mineral is heavy for its size, then it has a high specific gravity

(j) Magnetism

Is the mineral magnetic (try using a compass), or is it attracted by a magnet? This property is characteristic of Magnetite.

(k) Effervescence

When some minerals are exposed to acids, they begin to fizz (calcite).

(l) Birefringence

This is also known as double refraction. Birefringent minerals split the light into two different rays which gives the illusion of double vision in this Iceland Spar Calcite

(m) Fluorescence

Some minerals display the phenomenon of photoluminescence.

Table 2.5 : Relative abundance of important rock forming minerals

Minerals (arranged in the order of their crystallization)	Important constituents	Percent distribution
Primary minerals		
Ferro magnesium minerals		
Ortho-ino silicates		16.8
Olivine	Fe, Mg	
Pyroxenes	Ca, Na, Fe, Mg	
Amphiboles	Ca, Na, Fe, Mg, Al, OH	
Phyllo Silicates		3.6
Biotite	K, Fe, Mg, Al, OH	
Muscovite	K, Al, OH	
Non-Ferro Magnesium minerals		
Tecto Silicates		
Feldspars		61.0
Anorthite	Ca, Al	
Albite	Na, Al	
Orthoclase	K, Al	
Quartz		
Secondary minerals		
Clay minerals	Na, K, Ca	11.6
Others	Mg, Fe, Al, OH	6.0

2.9.2 Mineral Resource in India

India has access to a wide range of minerals. India has a large landmass and a variety of geological formations that favour the production of a wide range of minerals. Meher D.N. Wadia claims that "the mineral wealth of India, though by no means endless, is varied enough to provide for sound economic and industrial development of the country, but has at the same time, certain important deficiencies. There are reportedly close to 100 minerals that are known to be produced or worked in India, of which close to 30 may be regarded as more significant. This number includes several minerals that, despite being relatively unimportant in quality at the moment, are capable of material development in the future with the growth of industries. The nation has adequate supplies of manganese ore, titanium, aluminium, raw materials for refractories, and limestone, as well as fairly abundant reserves of coal, iron, and mica. However, there aren't enough deposits of the metals copper, lead, and zinc. There are nickel and tin deposits that are viable. India makes significant foreign exchange from the export of a wide range of minerals, including granite, titanium, manganese, iron ore, and bauxite. India must rely on imports to meet its needs for a variety of other minerals, including copper, silver, nickel, cobalt, zinc, lead, tin, mercury, limestone, platinum, graphite, and a great deal more.

India has 3,108 mines, of which 570 are for fuel (coal and lignite), 563 are for metallic minerals, and 1,975 are for non-metallic minerals. Over eight lakh people are employed in the mineral industry, which also contributes nearly three percent of the country's GDP and 11.5% of its industrial output. The mining industry gives a nation's industrial growth its necessary muscle. Although mining and mineral extraction had been popular in India for many years, the real growth only happened after Independence. Mining was boosted by the government's 1991 liberalisation policy, which also other economic activities. The new national mineral policy, announced in 1993 has conceded the demands of the private sector.

2.9.2.1 Types of minerals

Normally two types of minerals are recognised :

(i) Metallic Minerals : These minerals contain metal. Iron ore, copper, manganese, nickel, etc. are important examples of metallic minerals.

Metallic minerals are further sub-divided into ferrous and non-ferrous minerals.

(a) Ferrous Minerals : These minerals have iron content. Iron-ore, manganese, chromite, pyrites, tungsten, nickel, cobalt, etc. are important examples of ferrous minerals.

(b) Non-ferrous Minerals : These minerals do not have iron content. Gold, silver, copper, lead, bauxite, tin, magnesium, etc. are important examples of nonferrous minerals.

(ii) Non-metallic Minerals : These minerals do not contain metal. Limestone, nitrate, potash, dolomite, mica, gypsum, etc. are important examples of non-metallic minerals. Coal and petroleum are also non-metallic minerals. They are used as fuel and are also known as mineral fuels.

1. IRON ORE :

An all-purpose metal is iron ore. It is the foundation of contemporary civilization. It is the cornerstone of our fundamental industry and is utilised on a global scale. The consumption of iron is a measure of a nation's standard of living. In the form of iron ore, iron is extracted from mines. The proportion of pure iron in various types of iron ore varies. The following four types of iron ore are the most popular.

Production and Distribution

There are approximately 12,317.3 million tonnes of haematite and 5395.2 million tonnes of magnetite in the country's total in-situ iron ore reserves. Resources for very high grade ore are scarce and restricted primarily to the Bailadila sector of Chhattisgarh, with smaller amounts also found in the Bellary-Hospet region of Karnataka, Jharkhand, and Orissa. Orissa, Jharkhand, Chhattisgarh, Karnataka, Goa, Maharashtra, Andhra Pradesh, and Rajasthan are among the states that have haematite resources. Karnataka, Andhra Pradesh, Goa, Kerala, Jharkhand. Rajasthan, and Tamil Nadu all have magnetic resources.

Karnataka : The majority of India's iron ore production, or about one-fourth of it, is produced in Karnataka. Iron ore is widely distributed throughout the state of Karnataka, where production has increased by about three times since 1980. However, high grade ore deposits can be found in the Bababudan hills of Chikmagalur district, in the Kemmangundi area, and in the Bellary district's Sandur and Hospet. High grade haematite and magnetite comprise the majority of the ores. Shimoga, Dharwar, Tumkur, Uttar Kannad, and Chitradurga are some of the other significant producing areas.

Orissa : Over 22% of the iron ore produced in India comes from Oirssa. The districts of Sundargarh, Mayurbhanj, Cuttack, Sambalpur, Keonjhar, and Koraput have the most significant deposits. The Barabil-Koira valley contains 100 deposits spread across 53 sq km, making it the site of the richest haematite deposits in India. The haematites in the ores, which contain 60% iron, are abundant. Significant deposits are found close to Gorumahisani, Sulaipat, and Badampahar in the Mayurbhanj district; Banspani, Tahkurani, Toda, Kurband, Phillora, and Kiriburu in the Keonjhar district; close to Malangtoli, Kandadhar Pahar, Koira, and Barsua in the Sundargarh district; the Tomka range between Patwali and Kassa in the Sukind area.

Chhattisgarh : 18% of all iron ore reserves in India are located in Chhattisgarh. In the years 2002-2003, this state contributed about 20% of the nation's total production of iron ore. Iron ores are found all over, with Bastar and Durg district deposits being the most notable. These districts' reserves are thought to be in the neighbourhood of 4,064 million tonnes. These reserves are made of high-grade ore that has an iron content of more than 65%. Important producers include Dalli Rajhara in Durg district and Bailadila in Bastar district. In Bailadila, there are 14 deposits spread out over a 48 km long area running north to south. The Bailadila mine is the biggest mechanised mine in Asia, with reserves estimated to be 1,422 million tonnes. The ore is transported from the Bailadila pithead to the Vizag plant via a 270 km long steel pipeline. This has significantly lessened the pressure on the road route. High-grade ore from Bailadila is exported via Vishakhapatnam to Japan and other nations where it is in high demand. There are approximately 120 million tonnes of iron ore reserves in the 32 km long Dalli-Rajhara range. This ore's ferrous content is thought to be between 68 and 69 percent. The Hindustan Steels Plant in Bhilai is currently working with the deposits of this range. Surguja, Raigarh, and Bilaspur are additional iron ore-producing regions.

Goa : The beginning of iron ore production in Goa was relatively recent. Goa, which was once a non-entity, is now India's fourth-largest producer of iron ore. Although its reserves, which make up only 11% of India, are not particularly impressive when compared to other important producing states, it held the top spot among iron ore producers for a while before ceding this position to M.P. in the 1990s. Goa is currently in fourth place, behind Karnataka, Orissa, and Chhattisgarh in terms of iron ore production. Over 18% of India's current production comes from Goa. The Indian Geological Survey discovered 34 iron-bearing reserves in

1975, and the total ore deposits were estimated to be 390 million tonnes. In North Goa, Central Goa, and South Goa, there are almost 315 mines. Important deposits occur in Pirna-Adolpale-Asnora, Sirigao-Bicholim-Daldal, Sanquelim-Onda, KudnemPisurlem and Kudnem-Surla areas in North Goa; Tolsia-Dongarvado-Sanvordem and Quirapale-Santone-Costi in Central Goa; and Borgadongar, Netarlim, Rivona-Solomba and Barazan in South Goa. North Goa is where the richest ore deposits are found. The advantages of Marmagao port for exporting the ore and river transportation or ropeways for local transportation are available in these areas. Iron ore from Goa is primarily exported to Japan. The majority of the ore is low-grade siderite and limomite. Despite the iron ore's poor quality, the majority of mines are open-cast and mechanised, which allows for efficient iron ore exploitation. About 34,000 people depend on the mining of iron ore for their livelihood.

Jharkhand : Jharkhand accounts for 25 per cent of reserves and over 14 per cent of the total iron ore production of the country. Iron ore mining first of all started in the Singhbhum district in 1904 (then apart of Bihar). Iron ore of Singhbhum district is of highest quality and will last for hundreds of years. The main iron bearing belt forms a range about 50 km long extending from near Gua to near Pantha in Bonai (Orissa). The other deposits in Singhbhum include those of Budhu Buru, Kotamati Buru and Rajori Buru. The well known Noamandi mines are situated at Kotamati Buru. Magnetite ores occur near Daltenganj in Palamu district. Less important magnetite deposits have been found in Santhal Parganas, Hazaribagh, Dhanbad and Ranchi districts.

2. MANGANESE :

It is an important mineral which is used for making iron and steel and it acts as a basic raw material for manufacturing its alloy. Nearly 6 kilograms of manganese is required for manufacturing one tonne of steel. It is also used for the manufacture of bleaching powder, insecticides, paints, batteries and china-clay.

Production and Distribution

India has the second largest manganese ore reserves in the world after Zimbabwe. The total in situ reserves of manganese ore are 406 million tones out of which 104 million tones are proved, 135 million tonnes are probable and 167 million tones are in possible categories. The main reserves are found in Karnataka, followed by Orissa, Madhya Pradesh, Maharashtra and Goa. Minor occurrences of manganese ore in Andhra Pradesh, Jharkhand, Gujarat, Rajasthan and West Bengal.

Orissa : Orissa is the largest producer and produces over 37 per cent manganese ore of India. It is obtained from Gondite deposits in Sundargarh district and Kodurite and Khondolite deposits in Kalahandi and Koraput Districts. Manganese is also mined from the lateritic deposits in Bolangir and Sambalpur districts.

Maharashtra : It produces about 24 per cent of India's manganese ore. The main belt is in Nagpur and Bhandara districts. High grade ore is in Ratnagiri district.

Madhya Pradesh : Maharashtra is closely followed by Madhya Pradesh. About 11 per cent of India's manganese ore just two decades ago. The main belt extends in Balaghat and Chhindwara districts. It is just an extension of the Nagpur-Bhandara belt of Maharashtra.

Karnataka : About 13 per cent of India's manganese ore is produced by Karnataka. The main deposits occur in Uttara Kannada, Shimoga, Bellary, Chitradurg and Tumkur districts.

Andhra Pradesh : The share of Andhra Pradesh in India's manganese production has gone down from 8 per cent in 1977-78 to 4 per cent in 2002-03. The main belt is found between Srikakulam and Vishakhapatnam districts. Srikakulam district has the distinction of being the earliest producer (1892) of manganese ore in India. Cuddapah, Vijayanagaram and Guntur are other producing districts.

3. COPPER :

Copper was a metal that was used by humans much earlier than iron. Since ancient times, copper has been used to make coins and household items. It is widely used in a wide range of electrical machinery, wires, and cables because it is a good conductor of electricity and ductile. It is a crucial metal that is used by the defence and automotive industries. Additionally, it is alloyed to create stainless steel, "morel metal," and "duralumin" when combined with nickel, aluminium, and iron. It is known as "brass" when alloyed with zinc, and "bronze" when alloyed with tin. Copper ore can be found as veins, dissemination, and bedded deposits in both older and younger rock formations. Because most copper ores only contain a small amount of the metal, mining for copper is an expensive and time-consuming process. Indian ore grade typically averages less than 1% compared to the global average of 2.5% metal content (in the ore).

Production and Distribution :

Madhya Pradesh : Madhya Pradesh has surpassed Karnataka, Rajasthan, and Jharkhand to become India's top copper producer. The state produced 56.86% of the nation's total copper production in the fiscal year 2002-2003. The state is fortunate to have a sizable belt in the Taregaon region of the Malanjkhand belt of the Balaghat district. This district has a recoverable reserve of 1,006 thousand tonnes of metal and 84.83 million tonnes of copper ore. There are also modest-sized reserves in the Betul district's Kherlibazar-Bargaon region. There are reportedly copper ore reserves in a few other places as well.

Rajasthan : In terms of copper production, Rajasthan has also made significant advancements and now ranks second in India, contributing more than 40% of the nation's total output. Along the Aravali range is where the majority of copper reserves are located. The estimated 65.08 million tonnes of recoverable reserve in the state, distributed among the districts of Ajmer, Alwar, Bhilwara, Chittaurgarh, Dungarpur, Jaipur, Jhunjhunu, Pali, Sikar, Sirohi, and Udaipur, are expected to yield 613.55 thousand tonnes of metal. The most significant region for copper production is the Khetri-Singhana belt in the Jhunjhunu district. From Singhana to Raghunathgarh, this belt travels 80 km in a north-east to south-west direction, with an average width of 3 to 5 km. At Khetri, 1.8 million tonnes of copper ore are produced annually, producing roughly 16,000 tonnes of metal. Other significant producers are located in the Kho-Dariba area, which is 48 km to the southwest of Alwar, and the Delwara-Kirovli area, which is 30 km from Udaipur. 2.5 million tonnes of copper ore with a copper content of 0.60 percent have been estimated to be present in the Kishangarh area of the Ajmer district.

Jharkhand : Jharkhand, earlier a part of Bihar used to be the largest producer of copper till early 1980s but it has lost much importance and has slipped to third position, partly due to fall in its own production and mainly due to increased production of other states. The state's share of copper ore production has fallen from 62 per cent of the nation's total production in 1977-78 to a desperate 23% in 2002-03. The main copper belt extends over a distance of 130 km. Singhbhum is the most important copper production district where Rakha, Kendadih, Surda Dhobani, Mosabani and some other areas have proved reserves of 58,044 million tonnes from which 1,480.12 thousand tonnes of metal may be recovered. Hasatu, Baraganda, Jaradih, Paraspath, Barkanath etc. in Hazaribagh district; Bairakhi in

Santhal Parganas area and some parts of Palamu and Gaya districts are also reported to have some deposits copper ore.

4. BAUXITE :

An important ore used to produce aluminium is bauxite. It is an oxide of aluminium, and its name comes from the French town of Le Beaux. It is a rock made primarily of hydrated aluminium oxides rather than a specific mineral. It is a clay-like substance that, depending on the amount of iron present, can be pinkish, whitish, or reddish in colour.

Production and Distribution :

Orissa : The largest bauxite-producing state in India, Orissa accounts for more than half of the nation's total output. The state's total recoverable reserves are thought to be 1,370.5 million tonnes. The main bauxite belt is located in the districts of Kalahandi and Koraput and extends into Andhra Pradesh. The largest bauxite-bearing region in the nation is this 300 km long, 40 to 100 km wide, and 950 to 1300 metre thick belt. The principal deposits are found in the districts of Kalahandi, Koraput, Sundargarh, Bolangir, and Sambalpur. Chandgiri, Baphalimoli Parbat, Kathakal, Manjimali, Pasenmali, Kunnumali, Kodingandi, Pottangi, and Karalput in the Kalahandi and Koraput districts are some of the significant mining regions.The new aluminium plant in Damanjoli offers this region's bauxite a ready market. Adding fuel will be the proposed aluminium plant in Doragurha.

Gujarat : Gujarat is the second largest producer and produces over 15 percent of the total bauxite of India. The total reserves are estimated at 87.5 million tonnes mainly found in Jamnagar, Junagadh, Kheda, Kuchchh, Sabarkantha, Amreli and Bhavnagar. The most important deposits occur in a belt which is 48 km long and 3 to 4.5 km wide lying between the Gulf of Kachchh and the Arabian sea through Bhavnagar, Junagadh and Amreli districts.

Jharkhand : The estimated amount of recoverable bauxite reserves in Jharkhand is 63.5 million tonnes. These reserves can be found throughout large portions of the Gumla, Ranchi, Lohardaga, and Palamu districts. The districts of Dumka and Munger also contain a small amount of bauxite. In Lohardaga and the surrounding areas, high grade ore available.

Maharashtra : 10% of the bauxite produced in India overall is produced in Maharashtra. The state's total recoverable reserves are thought to be in the neighbourhood of 87.7 million tonnes. The plateau basalts are capped by the largest deposits, which are found in Kolhapur district. Rich deposits with an alumina content of 52 to 89 percent can be found in the Kolhapur district's Udgeri, Dhangarwadi, Radhanagari, and Inderganj. Thane, Ratnagiri, Satara, and Pune are the other areas with sizable deposits.

Chhattisgarh : Chhattisgarh produces more than 6 per cent bauxite of India. The Maikala range in Bilaspur, Durg districts and the Amarkantak plateau regions of Surguja, Raigarh and Bilaspur are some of the areas having rich deposits of bauxite.

Tamil Nadu : Estimated at 17.2 million tonnes, Tamil Nadu's bauxite reserves are concentrated in the Nilgiri, Salem, and Madurai districts. Tamil Nadu contributes just over 2% of India's bauxite thanks to the main bauxite-producing districts of Nilgiri and Salem.

5. LIMESTONE :

Rocks made of calcium carbonate, calcium and magnesium double carbonates, or a combination of these two elements are known as limestone. Limestone's main components, calcium and magnesium carbonates, are not its only constituents; it also contains trace amounts of silica, alumina, iron oxides, phosphorus, and sulphur. Except for Gondwana, almost all geological sequences from the Precambrian to the Recent contain limestone deposits that are of sedimentary origin. 1,69,941 million tonnes of limestone are estimated to be in-situ reserves overall, across all categories and grades.

Production & Distribution :

Madhya Pradesh : Madhya Pradesh is the largest producer of limestone and accounts for over 16 percent of the total limestone production of India. Large deposits occur in the districts of Jabalpur, Satna, Betul, Sagar, Damoh and Rewa. The total reserves of all grades of limestone are estimated to be over 1,500 million tonnes.

Rajasthan : Rajasthan has about 6 percent of the reserves and produces over 16 per cent of the total limestone of India. Jhunjhunu, Banswara, Jodhpur, Sirohi, Bundi, Ajmer, Bikaner, Dungarpur, Kota, Tonk, Alwar, Sawai Madhopur, Chittaurgarh, Nagaur, Udaipur and Pali are the main producing districts.

Andhra Pradesh : Andhra Pradesh possesses about one-third of the total reserves of the cement grade limestone in the country. Extensive deposits occurs in Cuddapah, Kurnool, Guntur, Krishna, Nalgonda, Adilabad, Warangal, Mahabubnagar and Karimnagar.

Gujarat : Gujarat has about 13 percent of the reserves but produces only about 11 percent of the total limestone of India. High grade limestone deposits occur in Banaskantha district. The other important producing districts are Amreli, Kachchh, Surat, Junagadh, Kheda and Panchmahals.

Chhattisgarh : Chhattisgarh accounts for more than nine per cent of total limestone of India Deposits of limestone occur in Bastar, Bilaspur, Raigarh, Raipur and Durg districts.

Tamil Nadu : Large scale reserves in Ramnathapuram, Tirunelveli, Tiruchchirappalli, Salem, Coimbatore, Madurai, and Thanjavur districts enable Tamil Nadu to provide more than eight per cent limestone of the country. Most of the deposits, except those of Salem district, are of cement grade limestone.

Karnataka : Gulbarga, Bijapur and Shimoga districts of Karnataka possess about one-third of cement grade limestone of India. Currently, this state produces a little less than one-tenth of the total limestone of India. The main producing districts of all grades of liemstone are Gulbarga, Chitradurg. Tumkur, Belgaum, Bijapur, Mysore and Shimoga.

6. DOLOMITE :

Dolomite is a term used to describe limestone that contains more than 10% magnesium; at 45%, it is considered to be true dolomite. Dolomite is primarily used economically in the metallurgical industry as refractories, blast furnace flux, a source of magnesium salts, and in the glass and fertiliser industries. Over 90% of dolomite is consumed by the iron and steel industry, which is followed in consumption by fertiliser (4%), ferro-alloys and glass (2% each), alloy steel (1%), and other uses (1%). Dolomite is widely distributed in the all parts of the country. The total in-situ reserves of all grades of dolomite are 7,349 million tones. The major share of about 90 percent reserves in distributed in the states of Madhya Pradesh, Chhattisgarh, Orissa, Gujarat, Karnataka West Bengal, Uttar Pradesh and Maharashtra. Production of dolomite has also shown tremendous increase like that limestone. From a meager 14 thousand tonnes in 1951 the production has increased 3,329 thousand tonnes in 2002-03.

Production & Distribution :

Orissa : Dolomite production in Orissa, which makes up about 29% of all production in India, is the largest in the country. A total of 562.6 million tonnes of recoverable dolomite of all grades are in reserve, of which 256 million tonnes are in the Birmitrapur locality alone. The main deposits are found in the districts of Sundargarh, Sambalpur, and Koraput. They are located in the Gangapur region, close to Sukra, and span a distance of about 100 km.

Chhattisgarh : Closely following Orissa is the state of Chhattisgarh which produces about 28 per cent dolomite of India. The recoverable reserves of all grades of dolomite are estimated to be 1,638 million tonnes. The main deposits occur in Bastar, Bilaspur, Durg and Raigarh districts.

Jharkhand : Dolomite occurs in bands to the north of Chaibasa in Singhbhum district. Some dolomite also occurs in Palamu district.

Rajasthan : Rajasthan produces 5.49 per cent of India's dolomite. Ajmer, Alwar, Bhilwara, Jaipur, Jaisalmer, Jhunjhunu, Jodhpur, Nagaur, Pali, Sawai Madhopur, Sikar and Udaipur are the main producing districts.

Karnataka : Karnataka produces slightly more than five per cent dolomite of India. Belgaum, Bijapur, Chitradurga, Mysore, Uttar Kannada and Tumkur contribute major part of the state's production.

7. MICA :

Mica, also known as abhrak, has been used as a medicine in Ayurveda since ancient times in India. Mica discovered new uses as the electrical industry developed. It is a valuable mineral in the electrical and electronics industries thanks to its insulating qualities. It has a low power loss factor and can withstand high voltage. Muscovite, phlogopite, and biotite are the three main types of mica found in India. Important pegmatite containing mica can be found in Rajasthan, Jharkhand, Bihar, and Andhra Pradesh. Mica in-situ reserves are estimated to be 59,065 tonnes overall. There are 42,626 thousand tonnes of mica in-situ reserves in Pradesh, 1,496 tonnes in Jharkhand, and 2,007 tonnes in Rajasthan.

Production and Distribution :

Rajasthan : Rajasthan is not as significant a producer of mica as Andhra Pradesh is, despite being the second-ranked state among those in India that produce the mineral. In 2002-2003, this state produced 190 thousand tonnes, or 15.61% of India. Jainur to Udaipur is the length of the principal mica belt. This has an average width of 96 km and a length of 322 km. Around Kumbbalgarh and Bhilwara, this belt widens. Tonk, Sikar, Dungamur, Bhilwara, Jaipur, and Ajmer are the principal producing areas.

Andhra Pradesh : Andhra Pradesh is the largest mica producing state of India. In 2002-03, this state produced 883 tonnes of mica which was more than 72 per cent of all India production. In the recent years, share of Andhra Pradesh has increased in respect to mica production. The mica belt lies in Nellore district and is 100 km long and 25 km wide. Nellore mica is generally light green in colour; it is generally stained and spotted. The other districts with workable mica deposits are Vishakhapatnam, West Godavari, Krishna (Tiruvur) and Khammam (Kallur). Shah mine in Gudur taluka is the deepest with mining being done at 300 m depth.

Jharkhand and Bihar : Earlier, Bihar was a very important producer of mica in India but it has lost much of its importance mainly due to formation of new state of Jharkhand and partly due to increased production in other parts of the country. Jharkhand is the third largest producer of mica in India. In 2002-03, this state produced 133 tonnes (or about 11 percent) of mica.

8. SILVER :

Another precious metal made in India is silver. Due to its softness and appealing white colour, it is valued for ornamentation next to gold. It had long been a significant form of money around the world. Additionally, it's used in the production of chemicals, electroplating, photography, and the colouring of glass, among other things. Agentine, stephanite, pyrargyrite, and proustite are the principal ore minerals for silver. It is frequently found in mixtures with different metals, including copper, lead, gold, zinc, etc.

India is not a major producer of silver. She produced 35,531 kg of silver valued at Rs. 23 crore in 1995-96. The major production comes from Zawar mines in Udaipur district of Rajasthan. Here, silver is obtained as a by-product during the concentration and smelting of galena ore in Hindustan Zine Smelter. The silver content varies from 171.4 gm to 774.5 gm per tonne of zinc and lead concentrates respectively. The Tundoo Lead Smelter in Dhanbad district of Jharkhand is another important producer of silver as a by product of lead. Some silver is produced by Kolar Gold Fields and Hutti gold mines in Karnataka during refining of gold. The Hindustan Copper Ltd. at Maubhandar smelter in Singhbhum district of Jhakhand obtains silver from copper slimes. Silver is also produced by Vizag Zinc smelter in Andhra Pradesh from the lead concentrates.

In the Jharkhand districts of Hazaribag, Palamu, Ranchi, and Singhbhum; the Andhra Pradesh districts of Cuddapah, Guntur, and Kurnool; the Gujarat districts of Vadodara, Bellary, and Jammu and Kashmir's Baramula; and the Uttaranchal districts of Almora, there are traces of silver.

9. GOLD :

It is a valuable metal which occurs in auriferous lodes and some of it is found in sands of several rivers. It is used for making ornaments and is known as international currency due to its universal use.

India's top gold-producing state is Karnataka. The state's recoverable gold ore reserves total 17.5 million tonnes, or 42,023 kg of metal, and are primarily located in the districts of Kolar, Dharwad, Hassan, and Raichur. It has also been reported that there are some gold reserves in the Gulbarga, Belgaum, Bellary, Mysore, Mandya, Chikmagalur, and Shimoga districts. About 88.7% of the gold produced in India was once produced in this state. Karnataka produced 2,705 kg of gold worth Rs. 1,232.3 million in 2002-2003. Although Karnataka's districts all have some gold reserves, the most significant reserves are in the Kolar Gold Fields, which account for about 57.75 percent of the state's total production. The Kolar Gold Field's deposits are spread out over an 80 km (north-south) long and 3–4 km wide belt, but the gold-bearing quartz veins are only found in a 6-7 km section near Marikuppam. The Kolar Gold Fields, where the first mining operations were carried out, are still India's main source of gold today. Approximately 3,539 thousand tonnes of gold ore with a gold content of 17,738 kg have been discovered during recent surveys by the Geological Survey of India for finding new lodes. The main gold mine at Kolar is among the deepest in the world, and as a result of the high cost of extraction, production from this mine is steadily declining. Additionally, very little gold remains in the mine because the majority of it has already been extracted. Currently, gold is present at depths greater than 3,000 metres, but its extraction at these depths is not economically feasible.

Though lagging far behind Karnataka, Andhra Pradesh is the second largest producer of gold in India. On the basis of the detailed mapping done by the Geological Survey of India in recent in the years, a total 7.06 million tonnes of ore and 37,025 kg gold metal have been assessed in the state. The main deposits are found in Ramagiri in Anantapur district. However, this field is almost exhausted. The other areas of gold deposits are Bisanattam and Chittoor district and Jonnagiri in Kurnool district.

In addition to the first two states, Jharkhand is a significant gold-producing state in India. In the years 2002-2003, this state produced 344 kg of gold, or more than 11% of all the gold produced in India. Both native and alluvial gold are found in Jharkhand. As implied by its name, the Subarnarekha (Gold Streak) River, Sona nadi in the Singhbhum district, and the streams draining the Sonapat valley are the sources of alluvial gold. Native gold can be found on the Chota Nagpur plateau near Lowa in the Singhbhum district.

In Himachal Pradesh's Shimla and Bilaspur, in Jammu and Kashmir's Kargil region near the Indus river's terraces and in alluvial and moraine deposits of the Dras river, in Madhya Pradesh's Balaghat and Seoni districts, in Chhattisgarh's Bastar, Raipur, and Raigarh, and in West Bengal's Purulia district, small amounts of gold are collected from the rivers.

2.10 Summary

Rock is the hard mass of mineral matter that form the essential part of the earth's solid crust. Rocks can be distinguished through their characteristics (colour, streak, hardness, cleavage, fracture and luster). According to the formation rocks are three types (i) Igneous, (ii) Sedimentary and (iii) Metamorphic rocks. Minerals have some distinct characteristics through which the minerals can be identified and classified. The Moh's depending on hardness in 1-10 scale minerals also can identified.

2.11 Questions/ Self-Assessment questions

1. What are the major characteristics of rocks?
2. Briefly describe different types of rocks?
3. How does sedimentary rock forms?
4. Describe types of minerals.
5. What is Moh's scale?
6. What are the Physical properties of minerals?
7. Describe the Relative abundancy of important rock forming minerals.

2.12 Suggested Readings

1. Pellant, C. (2002). Rocks and minerals. 2nd American ed. New York, Dorling Kindersley.
2. Merritts, D. J., Menking, K., & De Wet, A. (2014). Environmental geology: an earth systems science approach. Second edition. New York, W. H. Freeman and Company.
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4. Carla W. Montgomery (2011). Environmental geology. McGraw-Hill, Dubuque, IA,
5. https://www.bgs.ac.uk/discovering-geology/rocks-and-minerals/
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Unit - 3 ❑ Soil

Structure

3.1 Objectives

By successfully completing this unit, you will be able to :

- know the components of the soil and how does it form.
- visualize the weathering process and it types
- demonstrate the erosion process of soil
- understand the sedimentation process
- understand different structure and chemical composition of clay minerals
- know about the cation exchange capacity
- understand the soil contamination and its management from degradation

3.2 Introduction

As early as 5000 BC, the Vedas and Upanishad as well as other Indian literature mentioned soil as synonymous with land "the Mother" supporting and nourishing all life on earth. For a layman it is the dirt and dust on the surface of the earth. But for the farmer, soil is that portion of the earth's surface which he can plough and grow crops to provide him with food and fiber for his own needs and that of animals, to the poor man. For a mining engineer soil is debris covering the rocks. Engineers think that soil is any unconsolidated material removed in excavations and used for filling or provide foundation structure

Definitions :

Whitney (1892) : Soil is a nutrient bin which provides all the nutrients required for plant growth.

Hilgard (1892) : Soil is more or less loose and friable material in which plants, by means of their roots, find a foothold for nourishment as well as for other conditions of growth.

Simonson (1957) : The soil is three-dimensional body having length, breadth and depth which form a continuum over the land surface and differ gradually from place to place.

Soil Science Society of America (1970) :

(i) The unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for the growth of plants

(ii) Soil is the unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors viz. parent material, climate, macro and microorganisms and topography, all affecting over a period of time and producing a product, that is "SOIL" that differs from the material from which it is derived in physical, chemical, biological and morphological properties and characteristics.

3.3 Major component of soil

- Soil is composed of partly weathered, unweather, transformed products of rocks, rock minerals and organic matter.
- The mineral soil consists of four major components/phases: mineral material and organic matter (solid), water (liquid) and air (gases). In an ideal surface soil these components are observed in amounts (by volume, Fig. 3.1) as follows,

(i) Soild Phase (Mineral matter)

The solid phase is broadly composed of inorganic and organic constituents. The inorganic constituents which forms bulk of solid phase of soil includes silicates, carbonates, soluble salts and free oxides of Fe, Al and Si in addition to some amorphous silicates. Only a small fraction of the solid phase is of organic origin. The sources of organic constitutes are plant and animals. Of total volume, about half is solid space, 45 percent mineral matter and 5% organic matter.

(ii) Liquid phase (Soil water)

Forty to fifty per cent of the bulk volume of the soil body is occupied by soil pores, which may be completely and partially filled with water. The soil acts as a reservoir for supplying water to plants for their growth. The soil water keeps salts in solution which act as plant nutrients. Thus, liquid phase is an aqueous solution of salts.

(iii) Gaseous Phase (Soil air)

The air-filled pores constitute the gaseous phase of the soil system. The volume of the gaseous phase is thus dependent on that of liquid phase. The nitrogen and oxygen contents of soil air are almost same as that of atmospheric air but concentration of carbon dioxide is much higher.

The four major components of a typical soil exist mainly in an intimately mixed condition. The proportion of these components may vary from time to time and from place to place. The volume composition of sub-soil is different from the surface soil. Compared to top soils they are lower in organic matter content, lower in total pore space and contain a higher percentage of small pores. This means they have a higher percentage of mineral and water and considerable lower content of organic matter and air.

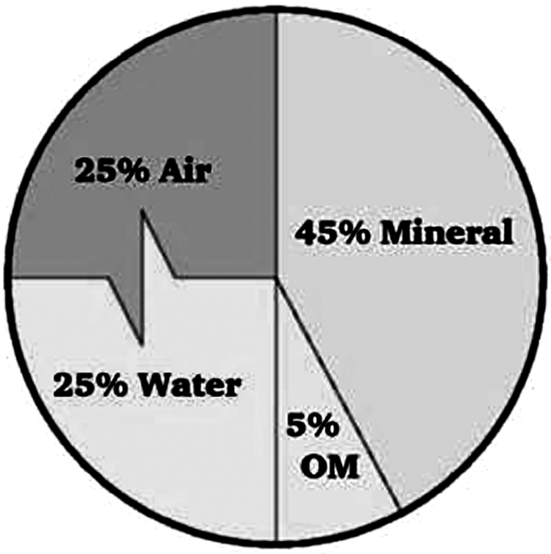

Figure 3.1 : Composition of surface soil

3.4 Soil Forming Processes

A. Fundamental Soil Forming Processes

(i) Humification :

- It is the process of transformation or decomposition of raw organic matter in to humus.
- In this process the soluble organic substances regroup themselves in to large molecules by polymerization and become poorly soluble.
- The characteristics are influenced by the nature of vegetation residue and the way it becomes decomposed and synthesized in to new organic compounds.

(ii) Eluviation (Latin, ex or e,out and lavere, to wash) :

- Eluviation means washing out. It is the process of removal of constituents in suspension or solution (Clay, Fe_2O_3, Al_2O_3, SiO_2, humus, $CaCO_3$, other salts *etc*) by the percolating water from the upper to lower layers. The Eluviation process involves mobilization and translocation of mobile soil constituents resulting in textural differences. Translocation depends upon relative mobility of elements and depth of percolation.
- The horizon formed by the process of eluviation is termed as eluvial horizon (A2 or E horizon).

(iii) Illuviation (Latin- il, in, and lavere, to wash) :

- The process of deposition of soil materials (removed from the eluvial horizon) in the lower layer is termed as Illuviation.
- This is the region of maximum accumlation of materials such as iron and aluminium oxides and silicate clays.
- The horizon formed by this process is termed as illuvial horizon (B-horizon, especially Bt).
- The process leads to horizon of gains and textural contrast between E and Bt horizons.

B. Specific Soil Forming Processes

The fundamental processes provide a framework for more specific processes like-

(i) Podzolization (Russian, pod means under and zola means ash)

- It is the process of eluviation of oxide of iron and aluminium (sesqui oxides) and also humus under acidic condition (pH 4-5), removal of carbonates by organic acids formed by organic matter and illuviation of the silicon in surface horizon.

- Abudant organic matter, commonly found under forest, cold and humid climate are favourable for the formation of such soils.
- The eluvated horizon assumes a bleached grey colour and is left in highly acid, siliceous condition and, the term podzol has been used for such soils.

(ii) Laterization (Latin, later-a brick)

- The term laterite is derived from the word later meaning brick or tile and was originally applied to a group of high clay Indian soils found in Malabar hills of Kerala, Tamil Nadu, Karnataka, Madya Pradesh and Maharashtra.
- Laterization is inverse process to that of podzolization *i.e.*, the process that removes silica, instead of sesquioxides from the upper layers and thereby leaving sesquioxides to concentrate in the solum.
- The process operates under rain forests of tropical areas, warm and humid (tropical) climate and basic parent materials are favourable for such soils.
- It refers specifically to a particular cemented horizon in certain soils which when dried, become very hard, like a brick.
- Such soils (in tropics) when massively mixed with sesquioxides (iron and aluminium oxides) to an extent of 70 to 80 percent of the total mass, are called laterites or latosols (Oxisols).

(iii) Salinization

- It is the process of accumulation of salts, such as sulphates and chlorides of calcium, magnesium, sodium and potassium in soils in the form of a salty (salic) horizon.
- The intensity and depth of accumulation vary with the amount of water available for leaching.
- It is quite common in arid and semi arid regions.
- It may also take place through capillary rise of saline ground water and by inundation with seawater in marine and coastal soils.
- Salt accumulation may also result from irrigation or seepage in areas of impeded drainage.

(iv) Desalinization

- It is the process of removal of excess soluble salts from horizons that contained enough soluble salts to impair the plant growth.
- Drainage is essential for desalinization.

(v) Alkalization (Solonization)

- The process by which soils with high exchangeable sodium and $pH > 8.5$ are formed; often sodium carbonate and sodium bicabonate are formed in extreme cases.
- The soil colloids become dispersed and tend to move downward. The dispersion results in poor physical condition of the soil.

(vi) Dealkalization (Solodization)

- The process refers to the removal of Na^+ from the exchange sites. This process involves dispersion of clay. Dispersion occurs when Na^+ ions become hydrated.
- The process is effected by intensive leaching and degradation which takes place in older soils.

(vii) Calcification

- The process operates in arid and semi-arid regions and refers to precipitation and accumulation of calcium carbonate ($CaCO_3$) in some part of the profile. The accumulation of $CaCO_3$ may result in the development of a calcic horizon.
- Calcium is readily soluble in acidic soil water and/or when CO_2 concentration is high in root zone as :

$$CO_2 + H_2O = H_2CO_3$$

$$H_2CO_3 + Ca = Ca\ (HCO_3)_2 \text{ (soluble)}$$

$$Ca\ (HCO_3)_2 = CaCO_3 + H_2O + CO_2 \text{ (precipitates)}$$

(viii) Decalcification

- In regions where some water percolates through the soil profile, decalcification takes place leading to the formation of calcic horizon down below.
- In humid regions, calcium cabonate reacts with water containing dissolved

carbon dioxide to form soluble bicarbonate which may be completely leached out of the soil profile.

$$CaCO_3 + CO_2 + H_2O \text{ (insoluble)} = Ca(HCO_3)_2 \text{ (soluble)}$$

(ix) Carbonation

- It occurs when carbon dioxide interacts chemically with minerals. When carbon dioxide is dissolved in water, it forms weak carbonic acid.
- When carbonic acid comes in contact with the surface of the earth it dissolves large masses of limestone, creating caves and caverns.

(x) Gleization :

- The term glei is of Russian origin means blue, grey or green clay.
- The gleization is a process of reduction, due to anaerobic condition, of iron in waterlogged soils with the formation of mottles and concretions. Such soils are called as hydromorphic soils.
- The process is not dependent on climate (high rainfall as in humid regions) but often on drainage conditions.

(xi) Pedoturbation :

- It is the process of mixing of the soil.
  1. Faunal pedoturbation : It is the mixing of soil by animals such as ants, earthworms, moles, rodents, and man himself
  2. Floral pedoturbation : It is the mixing of soil by plants as in tree tipping that forms pits and mounds
  3. Argillic pedoturbation : It is the mixing of materials in the solum by the churning process caused by swell-shrink clays as observed in deep Black cotton soils.

3.5 Weathering

Weathering is the combination of processes that breaking down of rocks, soil and minerals, eventually transforming into sediment. On the other hand, disintegration or alteration of the rock surface in its natural or original position through physical, chemical and biological processes induced or modified by wind, water and climate.

Weathering involves physical, chemical, and biological processes that act separately or more often together to cause fragmentation and decay of rock material. Physical decomposition causes mechanical disintegration of the rock and therefore depends on the application of force. Weathering involves breaking up the rock into the forming minerals or particles without disturbing the forming minerals. The main sources of physical Weathering are the expansion and contraction of heat, the erosion of overlapping materials, the release of pressure on the rock, alternatively the freezing and thawing of water, the dissolution of water between the cracks and cracks in the rock, the growth of plants and organisms in the rock. Organisms in the rock. Rock exchange usually involves chemical deterioration in which the mineral composition in the rock is altered, rearranged or redistributed. Rock minerals are subjected to solution, carbonation, hydration and oxidation with circulating water. These effects on the Weathering of minerals are added to the effects of living organisms and plants as nutrient extraction to rocks.

After the rock breaks, the remaining materials cause soil with organic materials. The mineral content of the soil is determined by the parent material; therefore, a soil derived from a single rock type may often be lacking in one or more minerals required for good fertility, whereas a ventilated soil from a mixture of rock types (such as glacial, aeolian or alluvial deposits) generally makes more fertile soils. In addition, most of the Earth's landforms and landscapes are the result of decomposition processes associated with erosion and re-accumulation.

Explain the disintegration or dissolution of rocks and minerals on the Earth's surface. Water, ice, acids, salts, plants, animals and changes in temperature are all weather conditions.

After a rock is shredded, a process called erosion removes rock and mineral fragments. No rock on earth can resist erosion.

Weathering and erosion constantly changes the rocky landscape of the Earth. Wear abrades exposed surfaces over time. Exposure time generally contributes to how vulnerable a rock is to weather conditions. Rocks buried under other rocks, such as lava, are less susceptible to wear and erosion than rocks exposed to wind and water.

It is the first step in soil production in weather conditions as it smooths hard, sharp rock surfaces. Small pieces of worn minerals mix with plants, animal remains, fungi, bacteria and other organisms. A single type of weathered rock generally produces infertile soil, the weathered materials from the rock collection are richer in mineral diversity and contribute to more fertile soil. Soil types associated with the weathered rock mixture include untouched and alluvial deposits until icing.

3.5.1 Types of weathering

Weathering is the breaking apart of rocks that are exposed at Earth's surface. Rocks cannot be weathered unless they are at Earth's surface and exposed to the hydrosphere, biosphere, and atmosphere. Weathering can break down rocks into fragments of varying sizes. Weathering is also responsible for the formation of sedimentary rocks. The process of weathering creates the sediments needed to form these rocks.

Weathering can take place in a variety of ways, which are classified into two main groups :

(a) Physical weathering or Mechanical weathering

(b) Chemical weathering

(c) Biological weathering

A. Physical weathering or Mechanical weathering

Physical weathering, also called mechanical weathering or disaggregation, is a class of processes that cause rocks to break up without chemical change. The primary process in physical weathering is abrasion (the process by which clips and other particles are reduced in size). Temperature, pressure, freezing and so on. Physical weathering may occur for reasons. For example, cracks resulting from physical weathering will increase the surface area exposed to the chemical effect, thereby increasing the rate of disintegration.

(i) Frost wedging

Freezing water blows pipes and breaks bottles; because water expands when the walls of the container freeze and push. The same phenomenon occurs on the rock. When stuck water in a joint freeze, it forces the joint to open and may cause the joint to grow. These freezing wedges allow the blocks to be freed from solid bedrock.

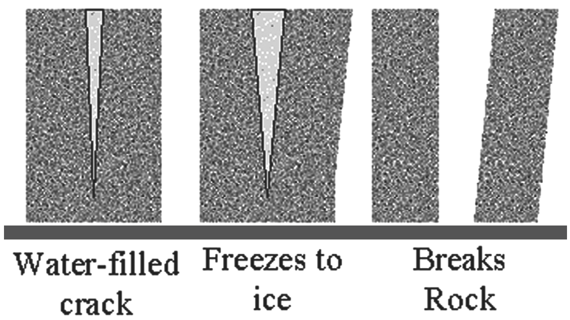

Figure 3.2 : Frost wedging

(ii) Salt wedging

In arid climates, dissolved salt in groundwater precipitates and grows as crystals in open pore spaces in rocks. This process, called salt wedging, pushes apart the surrounding grains and weakens the rock so that when exposed to wind and rain, the rock disintegrates into separate grains. The same phenomenon happens along the coast, where salt spray percolates into rock and then dries.

Figure 3.3 : Salt wedging

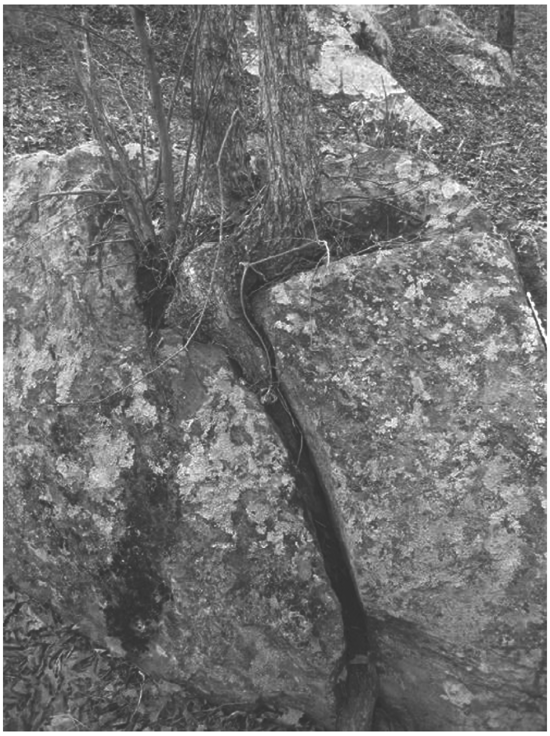

Figure 3.4 : Root wedging

(iii) Root wedging

Have you ever noticed how the roots of an old tree can break up a sidewalk? As roots grow, they apply pressure to their surroundings, and can push joints open in a process known as root wedging

(iv) Thermal expansion

When the heat of an intense forest fire bakes a rock, the outer layer of the rock expands. On cooling, the layer contracts. This change creates forces in the rock sufficient to make the outer part of the rock break off in sheet-like pieces. Recent research suggests that the intense heat of the Sun's rays sweeping across dark rocks in a desert may cause the rocks to fracture into thin slices (Fig 3.5).

(v) Animal attack

Animal life also contributes to physical weathering : burrowing creatures, from earthworms to gophers, push open cracks and move rock fragments. And in the past century, humans have become perhaps the most energetic agent of physical weathering on the planet. When we excavate quarries, foundations, mines, or roadbeds by digging and blasting, we shatter and displace rock that might otherwise have remained intact for millions of years more.

Figure 3.5 : Thermal expansion

Figure 3.6 : Weathering caused by Animal attack

B. Chemical weathering

Chemical weathering changes the composition of rocks, often transforming them when water interacts with minerals to create various chemical reactions. Chemical weathering is a gradual and ongoing process as the mineralogy of the rock adjusts to the near surface environment. New or secondary minerals develop from the original minerals of the rock. In this the processes of oxidation and hydrolysis are most important. Chemical weathering is enhanced by such geological agents as the presence of water and oxygen, as well as by such biological agents as the acids produced by microbial and plant-root metabolism.

The process of mountain block uplift is important in exposing new rock strata to the atmosphere and moisture, enabling important chemical weathering to occur; significant release occurs of Ca^{2+} and other ions into surface waters.

(i) Dissolution

Chemical weathering during which minerals dissolve into water is called dissolution. Dissolution primarily affects salts and carbonate minerals but even quartz dissolves slightly.

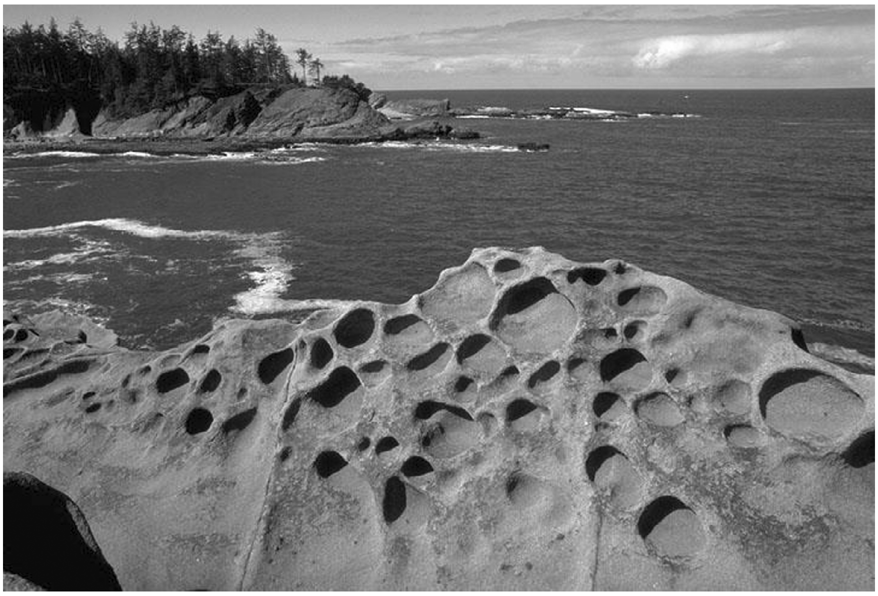

Figure 3.7 : Weathering caused by Dissolution

(ii) Hydrolysis

During hydrolysis, water chemically reacts with minerals and breaks them down (lysis means loosen in Greek) to form other minerals. For example, hydrolysis reactions in feldspar produce clay.

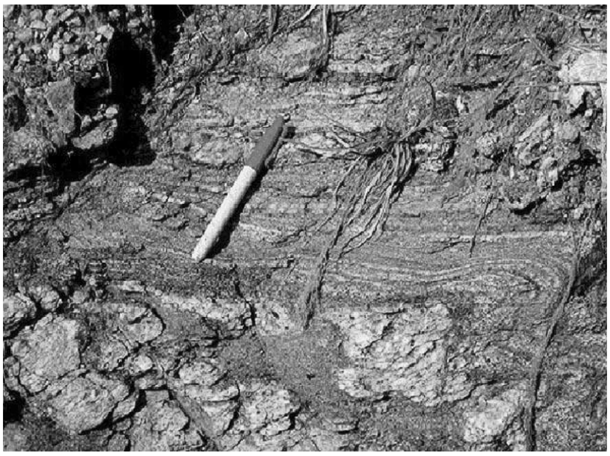

Figure 3.8 : Hydrolysis

(iii) Oxidation

Oxidation reactions in rocks transform ironbearing minerals (such as biotite and pyrite) into a rustybrown mixture of various iron-oxide and iron-hydroxide minerals. In effect, iron-bearing rocks can "rust."

Figure 3.9 : Weathering caused by oxidation

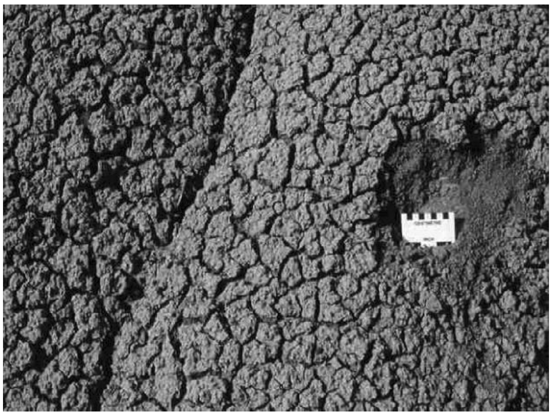

Figure 3.10 : Weathering caused by Hydration

(iv) Hydration

The absorption of water into the crystal structure of minerals, causes some minerals, such as certain types of clay, to expand. Such expansion weakens rock.

C. Biological Weathering :

Plants and Animal including human being are vastly responsible for weathering of rocks to the way of soil formation. These living community continuously disturbing, breaking down and reshaping the rock mass and soil. According to B. B. Polynov, in the world sterile weathering is impossible. Biotic weathering is subdivided into 3 types, these are —

(i) Weathering by Faunal Group

Each and every minute our land surface is altering by some animals who dig burrows. Earthworms, Prairie dogs, crabs, foxes, jackals, dogs, cats, cows, termites who use to dig burrow, tunnel or graze on land are responsible for physically breakdown of rock. They repeatedly mix fresh materials of soil and set a turbation process by which the lower surface material comes to the surface and upper materials to deeper place.

It's experimented that about 1,50,000 small and large creatures live in one acre of land who brings IStonnes of fresh soil at surface from below every year. In English garden, about 25.4 thousand kilograms of soil is brought to surface by various organisms, according to sir Charles Darwin.

(ii) Weathering by Floral Community

Vegetation community exists everywhere on the earth surface all over the world. Vegetation alters surface and disintegrate in two ways—

1. When plant roots grow up and travel downward in opposite direction of gravity, they place pressure on rock layer and make numberless cracks and joints. The rock layer, sometime can be said the parent rock starts to breakdown through those graduals widen cracks and joint made by vegetation roots. This is a type of Physical weathering formed by Vegetation (Biotic element).
2. Roots help in extracting nutrients by chelation process where a viscose liquid comes out from root and added to soil. At that time soil may affected by hydration, chelation or hydrolysis type chemical weathering. Beside that in dense forest the ground surface become humus rich and wet due to unavailability of proper sunlight which is a favourable condition for chemical weathering of soil.

(iii) Weathering due to Anthropogenic Activity

In modern society human are enriched with high technology, become a great reason of weathering and erosion of soil. We are rushing towards development rather than sustainable development which triggers the weathering and erosion rate at high speed. Minerals are mining at different places using technology enhanced machines, ploughing for agriculture, blasting of mountains for develop new roads, industry or town, uprooting or cutting down trees are very rigor reason behind weathering and erosion. We found landslides, mass movement, slumping, debris fall every year at different place which are end result of this unsustainable development process. Millions of years ago the earth was a hard surfaced planet where there was no presence of any vegetation or animals. Gradually rocky surface got weathered by different agents like temperature, water, wind through different way like physical and chemical weathering and transported from one place to another according to slope due to gravity and give birth to the element named 'Soil'. Soil is that place where vegetation and animal can take birth and grow up. Over time all types of weathering process works and as a result we gate soil to make our house, cultivate food, transport system to migrate and mines to quarry valuable minerals for development of nation.

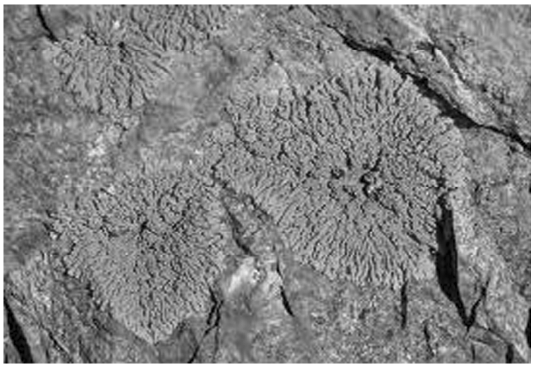

Figure 3.11 : Biological weathering

3.6 Erosion

What Is Erosion?

Erosion is a geological process in which earthen materials (*i.e.*, soil, rocks, sediments) are worn away and transported over time by natural forces such as water or wind; sometimes this is sped up by poor management or other human impacts on land. The natural process of river erosion, in fact, created the Grand Canyon, as the Colorado River cut deep and wide through the rock over millions of years, and glacial erosion carved Yosemite National Park's iconic landscape. (The difference between weathering and erosion is that in the process of weathering, materials are worn away but not transported. And erosion is the opposite of deposition, when natural forces leave earthen materials behind.)

Soil erosion refers to the erosion of the top layer of dirt known as topsoil, the fertile material vital to life. The rate of soil erosion depends on many factors, including the soil's makeup, vegetation, and the intensity of wind and rain. Because our own activities can also influence the speed of soil erosion, we have the power (and the responsibility) to solve one of the planet's greatest environmental challenges.

3.6.1 Causes of Erosion

Soil erosion occurs primarily when dirt is left exposed to strong winds, hard rains, and flowing water. In some cases, human activities, especially farming and land clearing, leave soil vulnerable to erosion. For example, when farmers till (plow) the soil before or after growing a season of crops, they may leave it exposed to the elements for weeks or months. The overgrazing of farm animals like cattle and sheep can also leave large areas of land devoid of ground-covering plants that would otherwise hold the soil in place. Another practice that has devastating consequences for soil health is deforestation, particularly clearcutting, a widespread practice of the industrial logging industry. When trees are cleared away, the land is left exposed to wind and rain without the security of roots to prevent the soil from being swept away.

Climate is also a major driver of erosion. Changes in rainfall and water levels can shift soil, extreme fluctuations in temperature can make topsoil more vulnerable to erosion, and prolonged droughts can prevent plants from growing, leaving soil further exposed.

3.6.2 Water Erosion

Water erosion occurs when rain or snowmelt displaces the soil on the ground. The more water flowing over the land, the more soil particles are moved or transported away. Land that has no vegetation— including farm fields that are left barren after crop harvest— are especially vulnerable to water erosion. Since there's no vegetation to absorb the water, hold dirt in place, or break up the energy of falling raindrops, a rainstorm leads to increased runoff and erosion. Intense weather events (heavy rains, flash floods, and rapid snowmelt) can lead to more rapid soil erosion.

For water to cause erosion and harm to farm fields, several factors come into play. Damage is more likely to occur if a great deal of rainfall and water runoff flows over the land during storms. Soil type, quality, and texture—the combination of soil particle size and how loosely or densely the particles are compacted—also influence the erodibility of a field's soil. Other factors are the length and slope of a piece of land, which can affect the speed and strength of water runoff. (That's one reason farms built on steep hillsides— often as a result of limited arable land— can be susceptible to devastating soil erosion and washouts.)

Vegetation— typical cropping as well as the strategic use of cover crops— can buffer the impact water has on a farm field. Land managers may also mitigate soil erosion through selective tillage practices. Typically, farmers till their soils to prepare fields for seed planting, control weeds, and retain moisture. But decades of agricultural research have revealed that a less-is-more approach may be the best way to minimize soil erosion. In other words, reducing mechanical disturbance to farm fields may help preserve soil.

3.6.2.1 Common Forms of Water Erosion

Water, though vital for life and agriculture, can be incredibly corrosive. Every raindrop splash has the potential to impact the structure of soil. Below are four common types of water erosion.

Figure 3.12 : Sheet erosion

(i) Sheet erosion

The removal of soil in thin, uniform layers (sheets) by raindrop impact and shallow surface water flow. Sheet erosion can sometimes be difficult to detect unless the soil is deposited nearby or if the damage is already severe. This erosion process removes the fine soil particles that contain most of the important nutrients and organic matter.

Figure 3.13 : Rill erosion

(ii) Rill erosion

It is a type of erosion that results in small yet well-defined channels—typically smaller than gully erosion channels. After some time, rill erosion may fade away or, in more serious cases, be smoothed over with tilling.

(iii) Gully erosion

Figure 3.14 : Gully erosion

Gully erosion is the washing away of soil through deep grooves or channels across unprotected land. Gully erosion can refer to soil being washed away through human-made drainage lines or describe the process of soil traveling through grooves created by hard rains. Farmers will typically fill these grooves back in with fresh soil as a temporary solution. As seen across the Midwest in 2019, gully erosion can hinder the ability to plow fields and grow crops.

(iv) Bank erosion

Bank erosion is the progressive undercutting, scouring, and slumping of natural rivers and streams as well as man-made drainage channels by the intense movement of water. When land managers remove vegetation or ranchers allow their livestock to overgraze the land near streams and riverbanks, it can exacerbate the problem. Bank erosion represents a serious threat to lands around the globe. For example, the claylike soil of southwestern Bangladesh is particularly vulnerable to erosion during the rainy season. Every year, riverbank erosion displaces tens of thousands of people and has a devastating impact on regional farming.

3.6.3 Wind Erosion

Figure 3.15 : Bank erosion

Wind erosion is a natural process that moves loose soil from one location to another. Very strong winds, in fact, can form large, destructive dust storms. Soils types that are loose, dry, and finely granulated are less desirable for farmland, as these qualities create smooth surfaces and increase erodibility. On the other hand, soil structure—roughness, clumps, and ridges—can help absorb wind energy and reduce erosion. Fields that are covered with vegetation or bordered by shrubs and trees (also known as shelterbelts) are also much less vulnerable, as the plants can help block wind. Last but not least, climate plays a big role in wind erosion: Studies suggest that a warmer climate would bring a greater risk of wind erosion on arid and semiarid lands.

3.6.3.1 Effects of Wind Erosion

Crop damage : When wind causes soil to become airborne, the blowing soil can sandblast delicate leaves and stems or even bury plants and seeds, resulting in decreased crop yields.

Dust storms : When dry, loose soil particles are suspended in the air, large dust storms can form and last for several hours. These storms can damage crops, harm livestock, and cause a variety of serious human health problems, including asthma attacks and dust pneumonia.

Adverse operating conditions : Dust storms can damage or impede the use of farm equipment and make it unsafe for agricultural workers to be in the fields.

Chemical drift : Wind can cause pesticides, herbicides, fertilizers, and various other agriculture chemicals to become airborne and move far beyond the intended area of application. This can be especially problematic for farmers trying to decrease chemical overuse on their fields, and for communities that live near farmland where many agrochemicals are applied.

3.6.4 Erosion Control Methods and Practices

Below are some common strategies for effective erosion control, many of which are part of the philosophy of regenerative agriculture. It's worth noting that finding appropriate erosion-control treatments relies on understanding which specific erosion processes are at play.

Build soil organic matter : To be healthy, soil needs just the right mixture of water, air, minerals, and organic matter. Soil organic matter, made up of decomposing plant and animal material, is the glue that helps bind soil together and keeps it anchored in place. Research suggests that increasing organic matter from 1 to 3 percent can reduce erosion by 20 to 33 percent because it increases the water-holding capacity of soil.

Plant vegetation : Trees, shrubs, hedgerows, and ground plants can block corrosive wind. Ensuring uninterrupted ground cover, such as through planting cover crops, also helps bind soil to roots.

Use erosion control matting : Also known as an erosion control blanket, this ground covering is often made of open-weave, biodegradable materials that shield the soil and provide support for growing vegetation on bare ground. This erosion control method is often effective for solar farms and construction sites where large areas are left barren and vulnerable to wind and water erosion.

Practice no-till/minimal tillage : Farmers have been plowing farm fields for centuries, but in recent decades agriculture scientists have helped prove that a no-tillage approach may offer more benefits. By not disturbing soil, farmers have been able to reduce erosion and runoff, which benefits crop productivity and water quality. No-till practices can also help reduce the loss of nitrogen and other vital soil nutrients.

Use grazing practices that reduce erosion : Rotational grazing is a method that moves livestock from one pasture paddock to the next. Each paddock gets a rest period and is allowed to regrow undisturbed, which minimizes soil compaction and erosion. Other beneficial practices include installing fencing and stream crossings to keep pastures safe from degradation.

3.7 Sedimentation

Sedimentation is the deposition of rock fragments, soil, organic matter, or dissolved material that has been eroded, that is, has been transported by water, wind, ice, or gravity.

A variety of human activities and environmental processes affect: rates of sedimentation, where sediment is deposited, and the nature of the deposited sediment, including :

- Rates of weathering and erosion, which are affected by climatic conditions, such as precipitation rates, snow and ice cover.
- Human land and water use, including deforestation and agricultural activities. For example, the damming of rivers changes where and how much sedimentation occurs, which affects soil quality and causes changes in habitats.
- The size and depth of the bodies of water, such as lakes, rivers, or the ocean, where the sediment is deposited. Slower rates of water flow lead to the deposition of finer grained sediments and to slower rates of deposition.
- Plants and other organisms, such as those that build coral reefs, can trap sediment that otherwise might be deposited elsewhere.

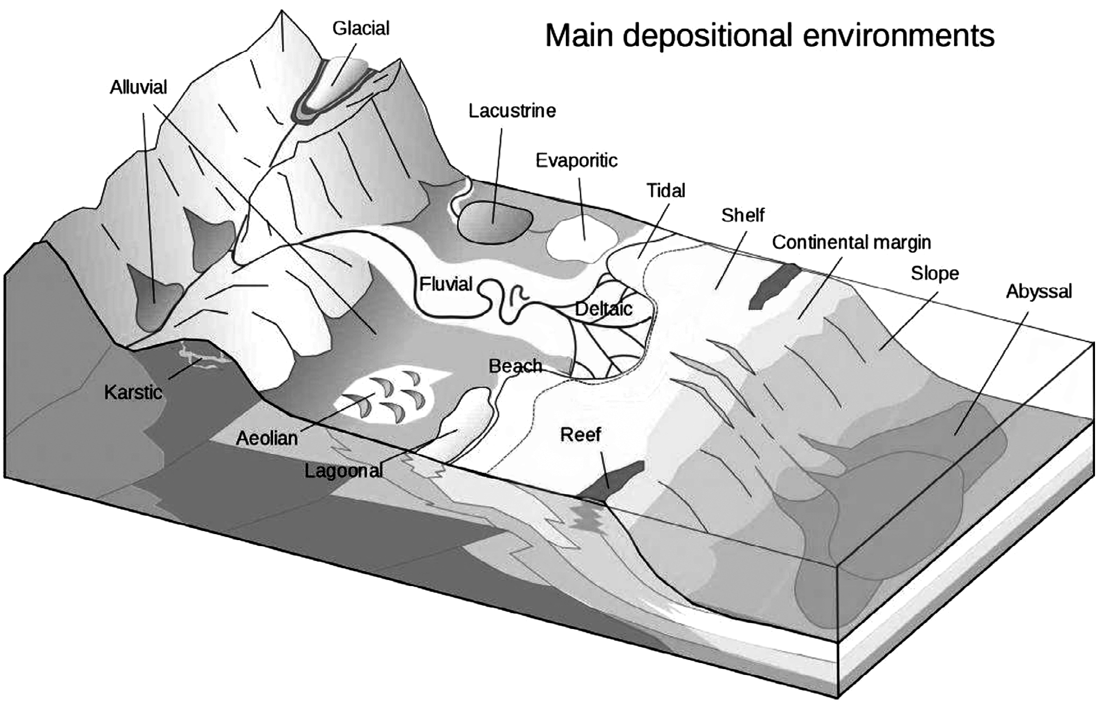

Figure 3.16 : Depositional environments where sediments accumulate. [Source : Wikimedia]

3.8 Identification and characterization of clay minerals

Clay minerals are one of the most common minerals in the earth. They are found in many different parts of the world, and they are used in a wide variety of applications. The identifying features and characteristics clay minerals are discussed in this unit.

3.8.1 Clay

Clay is a soft, freely bound, fine grained natural rock or earthy material having diameter less than 0.005 mm and composed essentially of clay particles. Based on the standard definition of mineral, clays are mainly inorganic materials except peat, muck, some soils, *etc*. that contain huge amount of organic/natural materials. The clay particles are formed due to the weathering and erosion of rocks containing soil, ceramic clays, clay shales, glacial clays (including great volume of detrital and transported clays) the mineral group feldspar (known as the 'mother of clay') over vast spans of time. During weathering, the content of feldspar is distorted by hydrolysis process results in formation of clay minerals such as kaolinites (the primary minerals in kaolin clays) and smectite (the primary minerals in bentonite clays). Clay can incorporate with one or more clay minerals even in presence of minute quantities of quartz (SiO_2), metal oxides (Al_2O_3, MgO *etc.*) and organic matter. The plasticity of clays are due to their particle size, geometry as well as content of water and become hard, stiff, coherent and non: plastic upon drying or firing. Plasticity and hardness are greatly affected by the chemical composition of the material present in the clay. Clays can be molded in any form when they retain water. For example, some species of chlorite and mica are found to be non-plastic while grinding macroscopic flakes even where more than 70% of the material is < 2 μm esd (equivalent spherical diameter). Whereas some species of chlorites and micas become plastic on grinding the macroscopic flakes where 3% of the materials is < 2 μm esd. Clays are easily molded into a form that they retain when dry, and they become hard and lose their plasticity when subjected to heat.

Mostly, geologic clay deposits composed of phyllosilicate minerals having variable amounts of water present in the mineral structure. The clay can appear in different form of colors from white to dull gray or brown to deep orange-red depending on the soil's content. The colloidal suspensions are formed when clays are immersed in water and flocculation occurs when they immersed in saline water.

Clays are divided into two classes :

Residual clay : Residual clays are found in the place of origin and formed by surface weathering which give rise to clay in three ways :

- Chemical decomposition of rocks, such as granite, containing silica and aluminia
- Solution of rocks, such as limestone, containing clayey impurities, which, being insoluble, are deposited as clay
- Disintegration and solution of shale

Transported clay, also known as sedimentary clay, removed from the place of origin by erosion and deposited in a new and possibly distant position.

3.8.2 Structure and chemical composition of clay minerals

The properties that define the composition of clay minerals are derived from chemical compounds present in clay minerals, symmetrical arrangement of atoms and ions and the forces that bind them together. The clay minerals are mainly known as the complex silicates of various ions such as aluminum, magnesium and iron. On the basis of the arrangement of these ions, basic crystalline units of the clay minerals are of two types :

silicon – oxygen tetrahedron consists of silicon surrounding by four oxygen atoms and unite to form the silica sheet.

aluminum or magnesium octahedron consists of aluminum surrounding by six hydroxyl units and combine to form gibbsite sheet (If aluminum is main dominating atom) or brucite sheet (If magnesium is main dominating atom) (Figure 3.17).

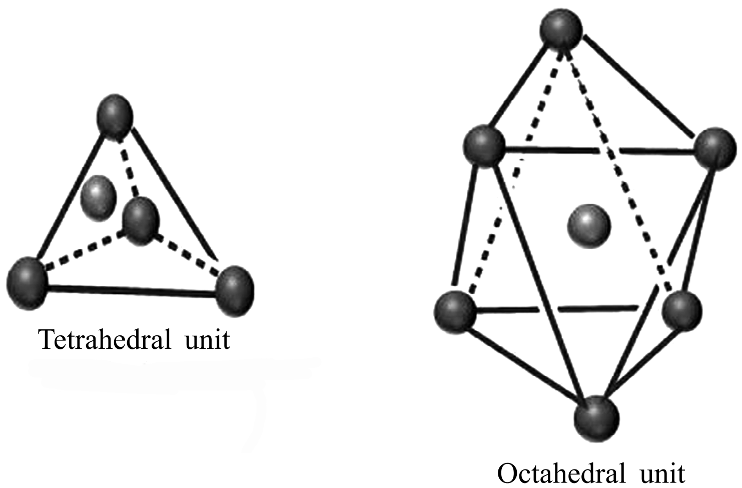

Figure 3.17 : Structure of tetrahedral and octahedral unit.

(a) Tetrahedral sheet

The main dominating atom in the tetrahedral sheet is found in form of Si4+ cation. The basic building block of tetrahedral sheet is a unit of Si atom surrounded by four oxygen atom known as silica tetrahedra. The tetrahedral sheet is formed by sharing of three oxygen of each tetrahedra with three nearest tetrahedra as shown in Figure 3.18. These oxygen atoms are known as basal oxygen which connect pairs of all tetrahedra together (more or less) in one plane whereas the fourth oxygen atom remain free and form the bond with other polyhedral elements known as apical oxygen. Apical oxygens are all in a separate plane and provide a link between both tetrahedral and the octahedral sheet. As only one apical O is present per tetrahedron therefore, each tetrahedron shares a corner with an octahedron in the octahedral sheet.

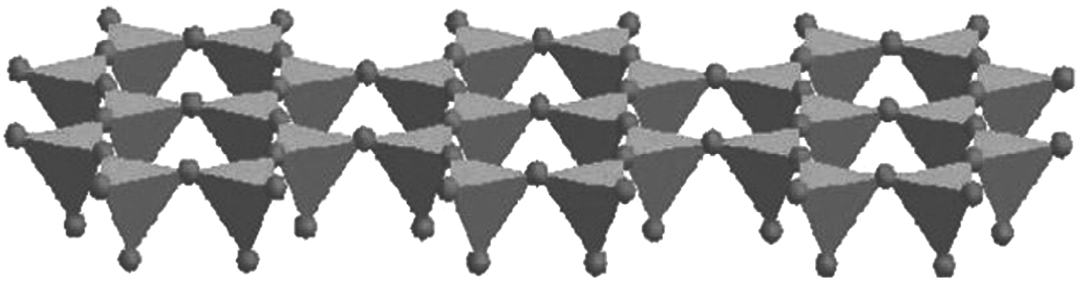

Figure 3.18 : Arrangement of tetrahedral unit to form the tetrahedral sheet.

(b) Octahedral sheet

The main dominating atoms in octahedral sheets are Al^{3+} or Mg^{2+} surrounded by six oxygen atoms or hydroxyl group give rise to eight-sided building block known as octahedron. Since, octahedral sheet is present in two forms: dioctahedral or trioctahedral sheet.

When aluminum having three positive valences present in the octahedral sheet, only two-thirds of the sites are filled so that the charges will be balanced which results in formation of dioctahedral sheet. When magnesium having two positive charge valences is present, all three positions are filled to balance the charge which results in formation of trioctahedral sheet. Therefore, for di – octahedral sheet, Al^{3+} is the main dominating atom with $Al_2(OH)_6$ a unit cell formula and often abbreviated as the stoichiometric equivalent $Al(OH)_3$ where two Al^{3+} atoms coordinated with six oxygen/or hydroxyl ions Arrangement of octahedral unit to form the octahedral sheet

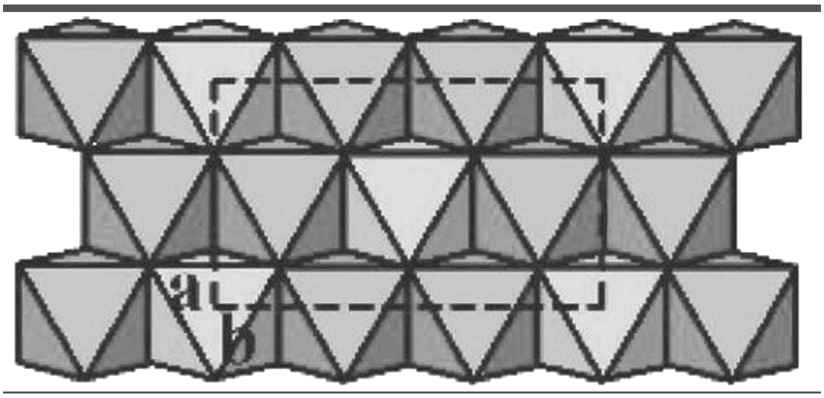

Figure 3.19 : Octahedral sheet

3.9 Cation Exchange Capacity

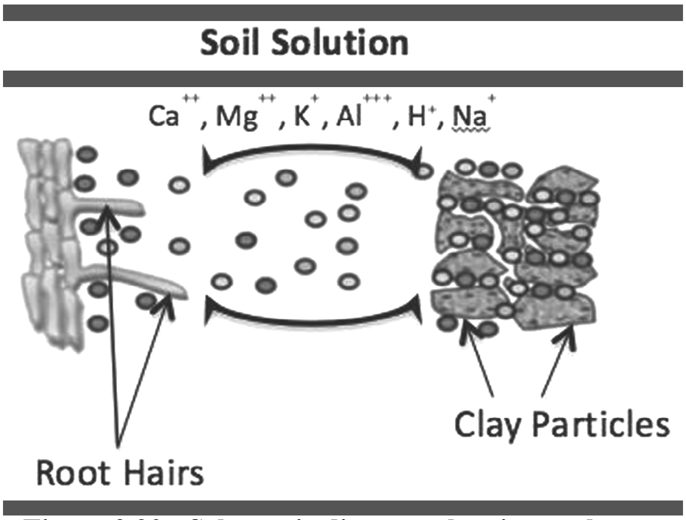

Figure 3.20 : Schematic diagram showing exchange of cations between the soil surfaces and the soil solution, and the movement of these cations from soil solution to roots (rhizosphere) for uptake

Soil clay minerals and organic matter tend to be negatively charged, thus attracting positively charged ions (cations) on their surfaces by electrostatic forces. As a result, the cations remain within the soil root zone and are not easily lost through leaching. The adsorbed cations may easily exchange with other cations in the soil solution, hence the term "cation exchange." The adsorbed cations replenish the ions in the soil solution when concentrations decrease due to uptake by plant roots.

Cation exchange capacity (CEC) is a measure of the total negative charges within the soil that adsorb plant nutrient cations such as calcium (Ca^{2+}), magnesium

(Mg^{2+}) and potassium (K^+). As such, the CEC is a property of a soil that describes its capacity to supply nutrient cations to the soil solution for plant uptake. Figure 3.18 illustrates cations retained on soil clay minerals that can exchange with those in the soil solution. Plant roots can remove nutrients from the soil solution, which results in nutrients moving away from the clay particles. Addition of fertilizer to soil causes an initial increase in nutrient concentration in the soil solution, which results in nutrients moving toward clay particles.

The nutrient cations plants use in the largest amounts are potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}). Other cations adsorbed on exchange sites are ammonium (NH_4^+), sodium (Na^+), hydrogen (H+), aluminum (Al^{3+}), iron (Fe^{2+} or Fe^{3+}), manganese (Mn^{2+}), copper (Cu^{2+}) and zinc (Zn^{2+}). Micronutrient cations such as zinc, copper, iron and manganese are typically present at very low concentrations in soils. Ammonium concentrations are also typically very low because microorganisms convert ammonium to nitrate in a process called nitrification.

3.9.1 How CEC changes with Soil pH

The CEC of soil organic matter and some clay minerals varies with pH. Generally, the CEC is lowest at soil pHs of 3.5 to 4.0 and increases as the pH is increased by liming an acid soil, as shown in Figure 3.21. Because CEC may vary considerably with soil pH, it is a common practice to measure a soil's CEC at a pH of 7.0. Also note that some positive charges may occur on specific soil mineral surfaces at low pH. These positive charges retain anions (negatively charged ions) such as chloride (Cl^-) and sulfate (SO_4^{2-}).

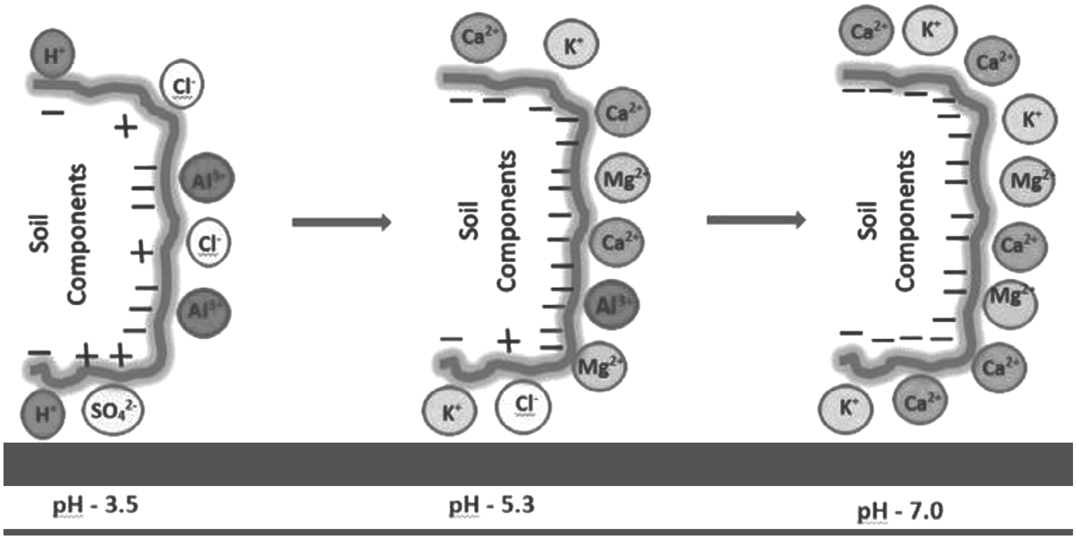

Figure 3.21 : Influence of pH on the surface charge of soil and its components.

3.9.2 Calculating the Cation Exchange Capacity from a Routine Soil Test

The CEC value included on typical soil testing laboratory reports is calculated by adding together the concentrations (expressed as milliequivalents of charge per 100 grams of soil) of potassium, magnesium, calcium, sodium and hydrogen, which are extracted from soils using an appropriate extraction method. The University of Georgia Soil Testing Laboratory uses the Mehlich I procedure, based on a double acid (0.05 N HCl + 0.025 N H_2SO_4) extracting solution. This method is appropriate for acidic, low CEC soils, which are commonly found in Georgia. The CEC of soils containing large amounts of clay or organic matter, or that are alkaline, cannot be satisfactorily analyzed using the Mehlich I extract. Other soil extraction methods should be used on these types of soils.

Table 3.1 : Cation exchange capacity and specific surface area of different clay minerals.

Cation-exchange capacities and specific surface areas of clay minerals		
Mineral	**Cation-exchange capacity at pH 7 (milliequivalents per 100 grams)**	**Specific surface area (square metres per gram)**
Kaolinite	3–15	5–40
Halloysite (Hydrated)	40–50	1,100*
Illite	10–40	10–100
Chlorite	10–40	10–55
Vermiculite	100–150	760*
Smectite	80–120	40–800
Palygorskite-sepiolite	3–20	40–180
Allophane	30–135	2,200
Imogolite	20–30	1,540

3.10 Soil testing and analysis

3.10.1 Soil Sampling

The first and most critical step in soil testing is collecting a soil sample. A soil analysis can only be as good as the sample sent to the laboratory. It is important to recognize what a tiny portion of a field is actually analyzed in the laboratory. For example, a 1 kg soil sample collected from a 5 acre field represents just 1/10,000,000 of the field! Therefore, it is vital that the soil sample be representative of the entire field. The most common and economical method for sampling an area is composite sampling, where sub-samples are collected from randomly selected locations in a field, and the subsamples are composited for analysis. The analytical results from composite sampling provide average values for the sampled area. The actual number of sub-samples depends on field size and uniformity. Generally, a larger field or a less uniform field should be more intensively sampled than one that is small and uniform. No less than 5 sub-samples should be taken from a sampled area, and 15 to 25 are preferable.

Alternatively, areas can be grid-sampled in a regular pattern. Each sample is analyzed separately, so that variability in soil properties can be determined. With data provided by grid sampling, maps of soil test values can be constructed. This information can be entered into a geographical information system (GIS) and combined with additional geospatial data, such as soil texture, crop yields, leaf analyses, *etc*. and used in precision agriculture systems for variable application of fertilizers and other crop inputs. This is a much more expensive method of soil analysis because of the large number of analyses required, although it provides valuable information about geospatial uniformity which can be used in precision agriculture.

Ideally, samples should be collected with a soil probe or auger (a small shovel or trowel can also be used), to the depth of tillage (usually 6 to 8 inches) or to the effective rooting depth of plants. Deeper samples may be collected for evaluation of subsoil properties, such as salt or nitrate accumulation. It is helpful to sample to the same depth each time a soil is sampled, so that year to year samples can be directly compared to monitor changes over time. Each sub-sample should be approximately equal in size. The sub-samples should be placed in a clean plastic bucket and mixed thoroughly. The desired sample amount is then removed from the bucket and the remainder discarded. Check with your testing laboratory to find out how large a sample they require.

The area or size of the field sampled is dependent upon management practices. Sample the smallest unit that will be managed separately. For example, if a field has two distinctly different sections, perhaps one half level and the other sloped, then sample the two areas separately, and fertilize each half separately to obtain optimum results. However, if each half of the area will not be fertilized or managed individually, there is no need for separate sampling. A single, representative sample will be less expensive and just as useful. Sample the smallest management unit.

Soil samples should be air-dried or taken to a test laboratory as soon as possible. To dry a soil sample, spread the soil out in a clean, warm, dry area, and let it dry for two to three days. It is best not to heat or dry soil samples in an oven because soil chemical properties may be altered. Bag the sample and send itto a laboratory for analysis. Soil samples can be refrigerated for several days if they cannot be dried immediately.

When is the best time of year to collect soil samples? Soil test values change slightly during the year, but the primary consideration for timing for most soil sample collection is convenience (nitrogen tests are an exception, see below). Collect samples early enough in the cropping cycle to allow results to be used to adjust management practices.

How frequently should soil samples be collected? The frequency with which soil samples should be collected depends on the specific soil test, environmental conditions, and value of the crop. Status of some soil nutrients can change quickly, whereas others do not. For example, phosphorus levels in soil are unlikely to change rapidly and annual testing may be unnecessary. Nitrogen levels, on the other hand, change very quickly and frequent tests are required to obtain accurate determinations of plant-available levels. A new soil analysis might be necessary after heavy rains or after a prolonged period of water-logging if one needs an accurate measure of soil nitrogen.

When making substantial changes to soil fertility levels, it is a good idea to make the change over a period of two to three years, retesting the soil annually.

If a crop does not have a high economic value, then occasional soil testing (once every 3 to 4 years) may be adequate in the absence of any noticeable nutritional problems. In contrast, commercial production of high value crops may warrant annual testing to ensure maximum yields.

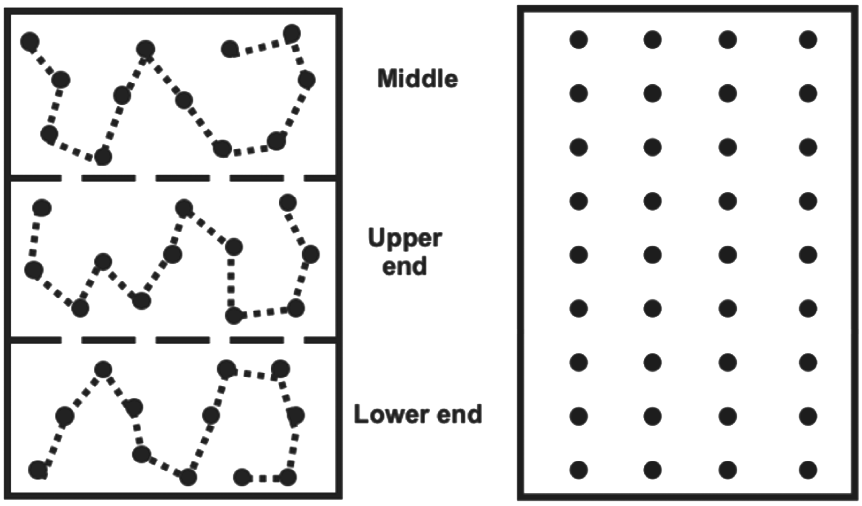

Figure 3.22 : On the left : dividing and sampling scheme for a sloped field with distinct upper, middle, and lower areas. Circles represent sub-sample locations which are composited for each of the three areas. On the right: grid-sampling a field. Each sample is analyzed separately to evaluate field variability.

3.10.2 Soil Analysis

Soil testing followed by accurate and reliable soil analysis data gives the knowledge of the chemical, physical and biological status of a soil that is fundamental to many of the management decisions made on the farm.

Soil testing enables the planning of cultivation and soil management actions as well as providing the basis for a sustainable crop nutrition programme that is accurate, timely and increasingly importantly environmentally responsible.

In short, soil testing provides the critical information required to ensure all crop nutrition decisions are accurate, efficient, cost-effective and responsible.

What to analyse?

Most of the work, and cost, of soil testing, is in the sampling and transportation of the samples to be analysed to the laboratory. Once the sample has arrived it makes sense to get as much information as possible from the sample.

1. Nutrient analysis

Soil testing provides an inventory of crop available nutrients and the background to build a nutrient management plan. Basic soil analysis (P, K, Mg and pH) is a legal requirement in England, but this analysis only provides a part of the picture as other nutrients and factors can be limiting to crop growth. In order to get the most from a soil sample, it is important to analyse for all nutrients using Yara's Broad Spectrum analysis group which includes the analysis for secondary nutrients, such as sulphur, and micronutrients

2. Chemical and physical analysis

The physical and chemical characteristics of the soil need to be considered before making any soil management decisions or planning a nutrient application strategy. Soil pH, Cation Exchange Capacity, organic matter and soil texture all have an impact on how we manage our soils and crops.

3. Biological analysis

An active population of soil organisms is essential to a healthy soil; they contribute to crop nutrition, recycling nutrients from the humus, organic matter and soil particles, as well as influencing soil structure. Together with the analysis of organic matter, a biological analysis provides a rounded picture of a soil's overall health, it's response to soil management practices and its potential for producing high yielding, quality crops.

3.11 Soil Contamination

Soil contamination is the occurrence of contaminants in soil above a certain level causing deterioration or loss of one or more soil functions. It occurs in two forms :

- 'Point pollution', caused by a specific event or series of events to a particular place, such as a former factory site. This is relatively well mapped and understood.
- 'Diffuse pollution', this involves low levels of contaminants spread over very wide areas that become lodged in the soil as it acts as a sink. This is difficult to analyze and track. Examples of such contaminants would be heavy metals or herbicides or pesticides used in agriculture.

Soil pollutants can consist of various forms, such as organic and inorganic or particulate pollutants.

3.11.1 What causes it?

Human activities

The most important sources of contamination in soils are those connected with human activities. Examples of point pollution include metal mining and smelting, industrial production, waste disposal and diffuse pollution examples include industrial activities, car emissions, application of agrochemicals, manure containing veterinary drugs, *etc*.

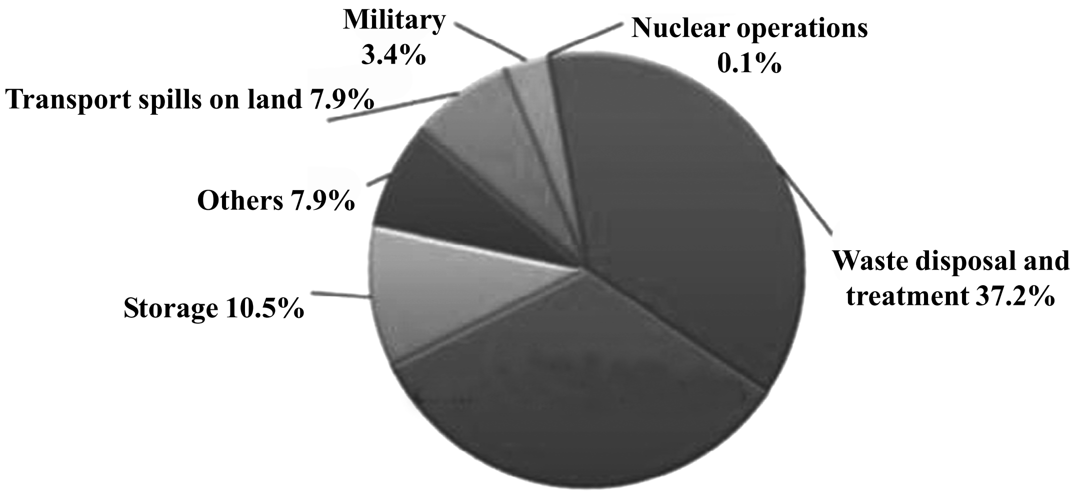

Figure 3.23 : Human activities

Municipal and industrial wastes contribute most to soil contamination (37%), followed by the industrial/commercial sector (33%). Mineral oil and heavy metals are the main contaminants contributing around 60% to soil contamination. In terms of budget, the management of contaminated sites is estimated to cost around 6 billion Euros (€) annually.

3.11.2 How can it be measured or assessed?

Table 3.2 : The table below shows the list of indicators for soil pollution

Topic	Problem	Indicator
Diffuse pollution by Inorganic pollutants	Which areas show critical heavy metal contents in excess of national thresholds?	Heavy metal contents in soils
Diffuse pollution by Inorganic pollutants	Are we protecting the environment effectively against heavy metal pollution?	Critical load exceedance by heavy metals
Diffuse pollution by nutrients and biocides	What are the environmentally relevant key trends in agricultural production systems?	Area under organic farming
Diffuse pollution by nutrients and biocides	Is the environmental impact of agriculture developing?	Gross nutrient balance
Diffuse pollution by persistent organic pollutants	Which areas show critical concentration of organic pollutants?	Concentration of persistent organic pollutants
Diffuse pollution by soil acidifying substances	How is the environmental impact of soil acidification developing?	Topsoil pH
Diffuse pollution by soil acidifying substances	Are we protecting the environment effectively against acidification and eutrophication?	Critical load exceedance by sulphur and nitrogen
Local soil pollution by point sources	How is the management of contaminated sites progressing?	Progress in management of contaminated sites
Local soil pollution by point sources	Is developed land efficiently used?	New settlements established on previously developed land
Local soil pollution by point sources	How many sites exist which might be contaminated?	Status of site identification
Filtering function of soil	What is the impact on soil function?	Cation exchange capacity
Filtering function of soil	Is there a loss of organic matter?	Organic matter content
Filtering function of soil	What is the actual availability of pollutants for plants and animals?	Bioavailability of pollutants

3.12 Soil conservation and management

Some of the less developed parts of the world employ slash-and-burn agriculture as well as other unsustainable subsistence farming techniques. Massive erosion, depletion of soil nutrients, and occasionally complete desertification are common effects of deforestation. Crop rotation, cover crops, conservation tillage, and installed windbreaks are methods for better soil conservation that have an impact on both erosions as well as fertility. Plants that die decompose and mix with the soil. For thousands of years, farmers have conserved their soil. In order to adequately address soil conservation in Europe, programmes like the Common Agricultural Policy focus on the adoption of best management practices including reduced tillage, winter cover crops, plant residues, as well as grass margins. To address the erosion issue, additional political and economic action is necessary. The way we value the land is a straightforward governance obstacle that can be overcome by cultural adaptation. As a carbon sink, soil carbon helps to slow down global warming.

3.12.1 Various Soil Conservation Methods

(i) Contour Ploughing

With contour ploughing, furrows are oriented to follow the contour lines of the farmland. Runoff is decreased because furrows shift to the left and right to keep a steady altitude. For slopes from two to ten per cent, the ancient Phoenicians used contour ploughing. Crop yields can rise by 10% to 50% with contour ploughing, in part due to better soil retention.

(ii) Terrace Farming

Creating almost level spaces on a hillside is a procedure known as terracing. The terraces are like a succession of steps, each one taller than the one before it. Other soil barriers shield terraces from erosion. Small farms tend to use terraced farming more frequently.

(iii) Keyline Design

The improvement of contour farming known as keyline design involves creating contour lines while taking into account all of the characteristics of the watershed.

(iv) Perimeter Runoff Control

By obstructing surface flows, ground cover, trees, and shrubs are efficient perimeter treatments for preventing soil erosion. The usage of a "grass path," which both channels and scatters runoff via surface friction, delaying surface runoff and enabling penetration of the sluggish surface water, is a unique kind of this perimeter or inter-row remedy.

(v) Windbreaks

On the windward side of a field of agriculture vulnerable to wind erosion, windbreaks are adequately thick rows of trees. Although, as long as leaves are present throughout the months of bare ground surfaces, the impact of deciduous trees may also be sufficient. Evergreen species offer shelter all year round.

(vi) Soil Conservation Farming

No-till farming, "green manures," and other soil-improving techniques are used in soil conservation agriculture, making it difficult to balance the soils. These farming techniques aim to replicate the biology of arid environments. They can restore depleted soil, reduce erosion, promote plant growth, do away with the need for nitrogen fertiliser and fungicides, yield yields that are above normal, and safeguard crops from drought and flooding. Less labour is required as a result, which lowers expenses and boosts farmers' earnings. Cover crops and no-till farming serve as nutrient sinks for nitrogen and other elements. Soil organic matter is increased as a result. Repeated tilling and ploughs destroy the soil's beneficial fungus and earthworms. Even under ideal conditions, it may take several seasons for soil to make a full recovery once it has been harmed.

(vii) Salinity Management

Irrigating using salty water contributes to the salinity of the soil. The salt is then left behind as the water is evaporated from the soil. Infertility and stunted growth result from salt's destruction of the soil's structure.

Below is the list of ions that cause the salinisation of soil:

Sodium (Na^+)

Potassium (K^+)

Calcium (Ca^{2+})

Magnesium (Mg^{2+})

and Chlorine (Cl)

One-third of the world's arable land is said to be affected by salinity. Crop metabolism is negatively impacted by salinity in the soil, and erosion frequently follows. Drylands become salinized as a result of excessive irrigation and in locations with low saline water levels. Over-irrigation accelerates the pace at which salts are deposited in the upper soil layers as a consequence of soil infiltration. Given the extensive irrigation, the use of humic acids might avoid oversalination. Both anions and cations can be fixed by humic acids, which then remove them from root zones. Lowering water tables can be utilised to slow the capillary and evaporative accumulation of surface salts by planting species that can withstand salty environments. Saltbush is a plant that can withstand salt and is widespread in Europe's Mediterranean regions as well as much of North America.

After the Aswan Dam was built in 1970, Egypt experienced the most well-known instance of shallow saline water table capillary activity. High salt contents in the water table were caused by the change in the groundwater level. Salinization of the soil was caused by the water table's persistently high level.

(viii) Soil Organisms

A healthy variety of minerals and plant nutrients are transformed into forms that roots can absorb when worms excrete their waste as casts. In comparison to the surrounding top 150 millimetres (5.9 in) of soil, earthworm excretes are 5 times higher in available nitrogen, 7 times higher in available phosphates, and 11 times higher in available potash. More than 4.5 kg of castings per worm could be produced annually. The earthworm increases soil porosity by burrowing, forming channels that help the aeration as well as drainage processes. To achieve high yields on degraded soil, synthetic fertiliser is needed. Lack of structure accelerates erosion and causes the pollution of rivers and streams with nitrogen. Every 1% increase in organic matter increases the capacity of the soil to hold 20,000.

Nematodes, mycorrhiza, and bacteria are further significant soil creatures. Of all animal species, approximately 25 per cent live underground. There are significant information gaps regarding soil biodiversity, as per the Food and Agriculture Organization's report, 2020 "State of knowledge of soil biodiversity – Status, challenges and potentialities".

(ix) Mineralisation

Active soil mineralisation is occasionally done in order to assist plants to reach their maximum phytonutrient ability. Broken rock or chemical soil additives may be added in this situation. Combating mineral depletion is the goal in both scenarios. A wide variety of minerals, from more familiar ones like zinc and selenium to less common ones like phosphorus, can be employed. The stage transformations of minerals within soil under aqueous contact have been extensively studied. An alluvial plain may get large sedimentation from flooding. While adding to a floodplain is a natural process that can revitalise soil chemistry with mineralisation, this impact may not be desired if floods endanger lives or if the silt comes from productive land.

3.13 Summary

Soil is the upper most layer of the earth crust and a nutrient bin which provides all the nutrients required for plant growth. Soil forms through humification, eluviation and illuviation process. Weathering is the combination of process that breaking down of rocks, soil and minerals. It took place in variety of way, which are classified in to physical weathering that involves physical process, chemical weathering that involves chemical process and biological weathering that in involves biota. Clay material are divided into two class residual clay and transported clay.

3.14 Questions/Self-Assessment questions

1. Why is soil conservation important?
2. What are effects of soil conservation?
3. What is pH level of soil?
4. How does the soil forms?
5. What do you know about eluviation and illuviation process?
6. Describe physical weathering process.
7. What do you mean by sedimentation?

8. Describe different structure prevails in clay minerals.
9. What is cation exchange capacity of soil?

3.15 Suggested Readings

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Unit - 4 ❑ Fundamentals of climatology

Structure

4.1 Objectives

By successfully completing this unit, you will be able to :

- know about different scale of meteorology.
- Understand the elements of climate
- Understand the Coriolis force and pressure gradient force
- visualize the Indian monsoon
- demonstrate Koppen's classification of climatic regions of India

4.2 Introduction

Weather is the condition of the atmosphere over a brief period of time. For example, we speak of today's weather or the weather this week. Climate represents the composite of day-to-day weather over a longer period of time.

A climatologist attempts to discover and explain the impacts of climate so that society can plan its activities, design its buildings and infrastructure, and anticipate the effects of adverse conditions. Although climate is not weather, it is defined by the same terms, such as temperature, precipitation, wind, and solar radiation.

Atmospheric scientists often subdivide study of complexity of gaseous envelope that surrounds the earth into specific areas of interest. One such division identifies the fields of meteorology and climatology. Meteorology is a science that deals with motion and the phenomena of the atmosphere with a view to both forecasting weather and explaining the processes involved. It deals largely with status of atmosphere over a short period of time and utilizes physical principles to attain its goal. Climatology is the study of atmospheric conditions over a longer period of time. It includes the study of different kinds of weather that occur at a place. Dynamic change in the atmosphere brings about variation and occasionally great extremes that must be treated on the long term as well as the short term basis. As a result, climatology may be defined as the aggregate of weather at a place over a given time period.

There is diversity of approaches available in climate studies. Figure 4.1. illustrates the major subgroups of climatology, the approaches that can be used in their implementation, and the scales at which the work can be completed.

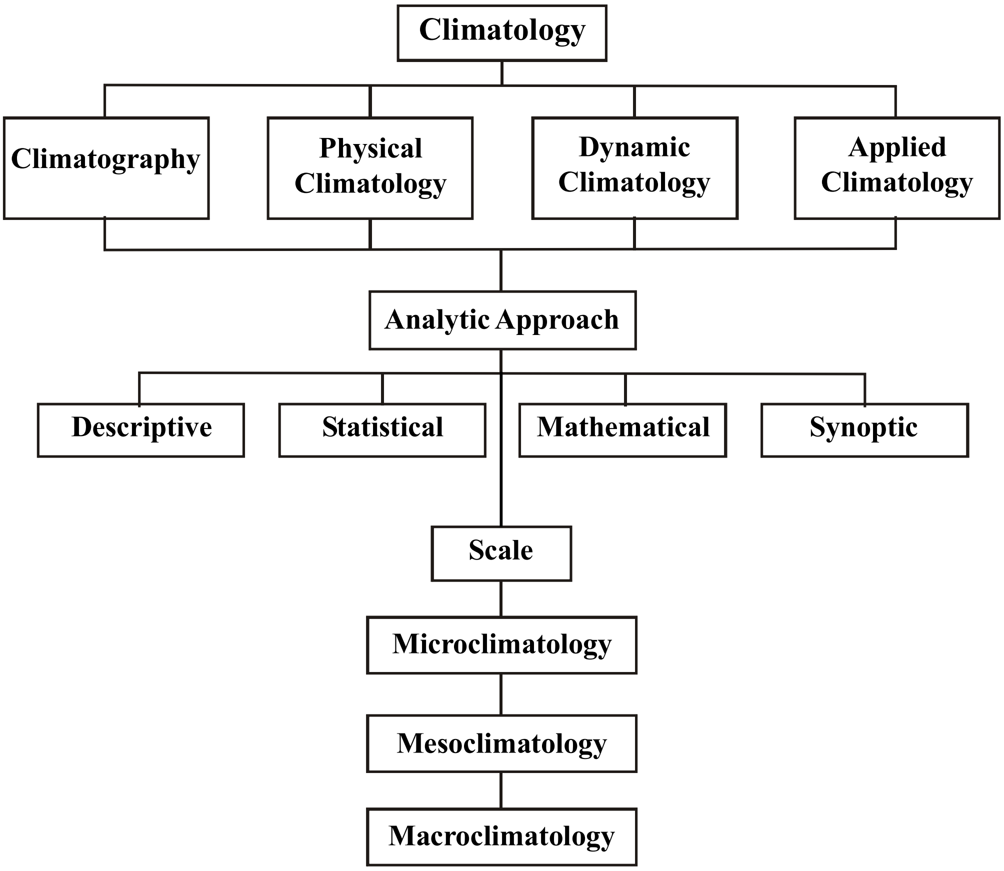

Figure 4.1 : Subgroups, Analytical methods and scales of climatic study.

[Source : J. E. Olive 1981, P4 used by permission of V. H. Winston and Sons.]

Climatography consists of the basic presentation of data and its verbal or cartographic description.

Physical Climatology deals largely with the energy exchanges and physical components.

Dynamic Climatology is more concerned with atmospheric motion and exchanges that lead to and result from that motion.

Applied Climatology is the scientific application of climatic data to specific problems within such areas of forestry, agriculture, and industry. It can involve the application of climatic data and theory of other disciplines, such as geomorphology and soil science.

The analytical approaches suggested in the above figure 4.1 are self-explanatory, with the possible exception of the synoptic approach, an analytic method that combines each of the others. The object of synoptic climatology is to relate local or regional climates to atmospheric circulation.

4.3 Scale of meteorology

The scale of meteorology is the spatial, but also the temporal scale of individual weather phenomena and their combination. In other words, when studying weather, meteorologists, as well as geographers and other scientists, use maps of different scales in order to better search, study, understand and predict these or those phenomena, focusing on a certain area whether it is a local phenomenon or the whole world. And this is very logical to study a small weather event, it is important to immediately draw its boundaries, which cannot be exceeded; a bigger one wider boundary, and so on all the way around the world.

Hence, there are four main scientific scales, including meteorology: microscale, mesoscale, macroscale, or synoptic, and megascale.

Important : we are talking about both horizontal weather scales from a few centimeters to the whole world, and vertical scales within the troposphere and the beginning of the stratosphere, that is, the first two layers of the atmosphere from the earth, which are actually where all weather phenomena are contained.

So, in this article, we will deal with all four types of meteorological scales. Let us say at once that these divisions are somewhat conditional, their boundaries may be blurred, and they also may not coincide in exact values with similar scales in other sciences.

4.3.1 Microscale meteorology — small or local

Microscale meteorology or micrometeorology (as well as small or local meteorology) studies the smallest weather phenomena on a scale of a few centimetres to a kilometer or a bit more, which lasts no more than a day (24 hours).

For example, soil temperature in some small areas, certain features of clouds of particular types, short-lived thunderstorms, local turbulence, and others, but more importantly, their relationships with each other or how one passes into the other.

This also includes, for example, the study of individual air pollutants, which are taken into account in calculating the Air Quality Index (AQI). Specifically, there are top five air pollutants in the US are ground-level ozone, particle pollution, carbon monoxide, sulfur dioxide, and nitrogen dioxide. So, this is the kind of weather phenomenon that cannot be depicted on a normal weather map. (Although there are air quality maps.)

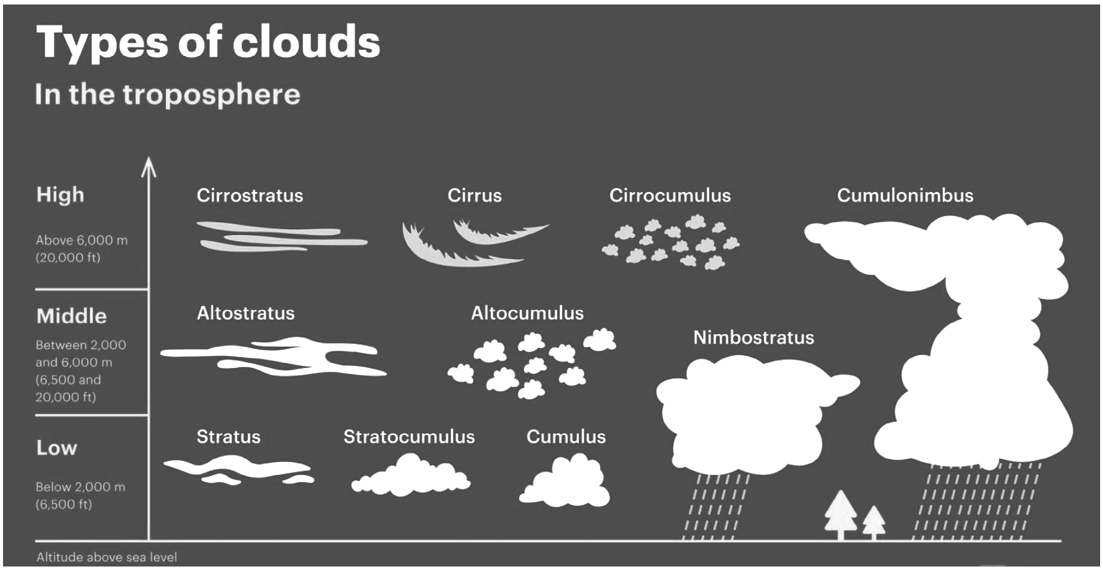

Figure 4.2 : Types of clouds. [Source : Valeriya Milovanova/Windy.app]

4.3.2 Mesoscale meteorology — medium or regional

Mesoscale meteorology or mesometeorology (as well as medium or regional meteorology) studies medium-scale weather phenomena from a few kilometers to several hundred and a thousand or two, but usually not more, that last from one day to several days to a week.

For example, these are weather fronts or collision boundaries of air masses of different temperatures, which refer to convection processes (circulation) in the atmosphere. They are of two main types — cold and warm. Fronts bring with them certain weather, but above all speak of its variability. Weather fronts can be as large as a medium-sized U.S. state such as Ohio.

This also includes weather phenomena such as large thunderstorms, squall lines, sea and land breezes, vortexes, and others.

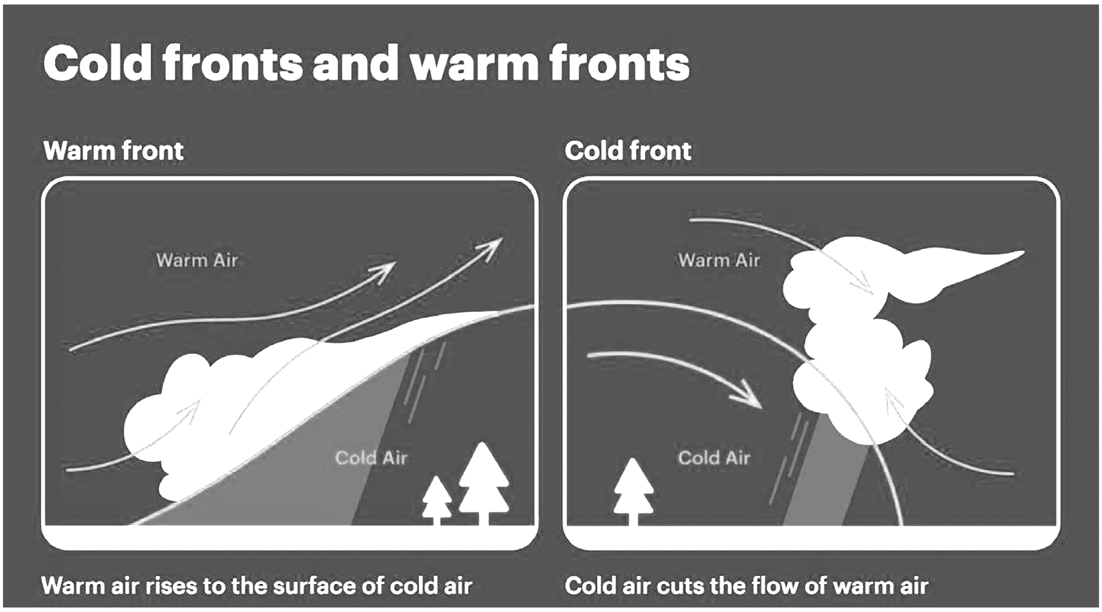

Figure 4.3 : Cold fronts and warm fronts.
[Source : Valeriya Milovanova/Windy.app]

4.3.3 Synoptic scale meteorology — large or national and continental

Macroscale meteorology more commonly called synoptic scale meteorology or large-scale meteorology (as well as national or continental) studies large-scale weather events of several hundred to several thousand kilometers that last up to several weeks. The word "synoptic", different from the other names, comes from the Greek word synoptikos, which means "seen together."

For example, it is atmospheric pressure or the force with which a column of air presses against the surface at a particular place on the earth. Hence it can be low or high, and cover vast areas. Like the circulation of air masses, pressure is the essence of large-scale weather events or systems such as tropical cyclones (hurricanes in North America and typhoons in Asia), heat and cold waves, and others. Cyclones can be the size of several states in the southeast U.S. or several countries in East Asia, which they basically go through every year.

This also includes another, rarer variety of cyclones — extratropical cyclones or mid-latitude cyclones, with a more self-speaking name. They also carry severe gales, thunderstorms, blizzards, tornadoes, and other extreme weather events.

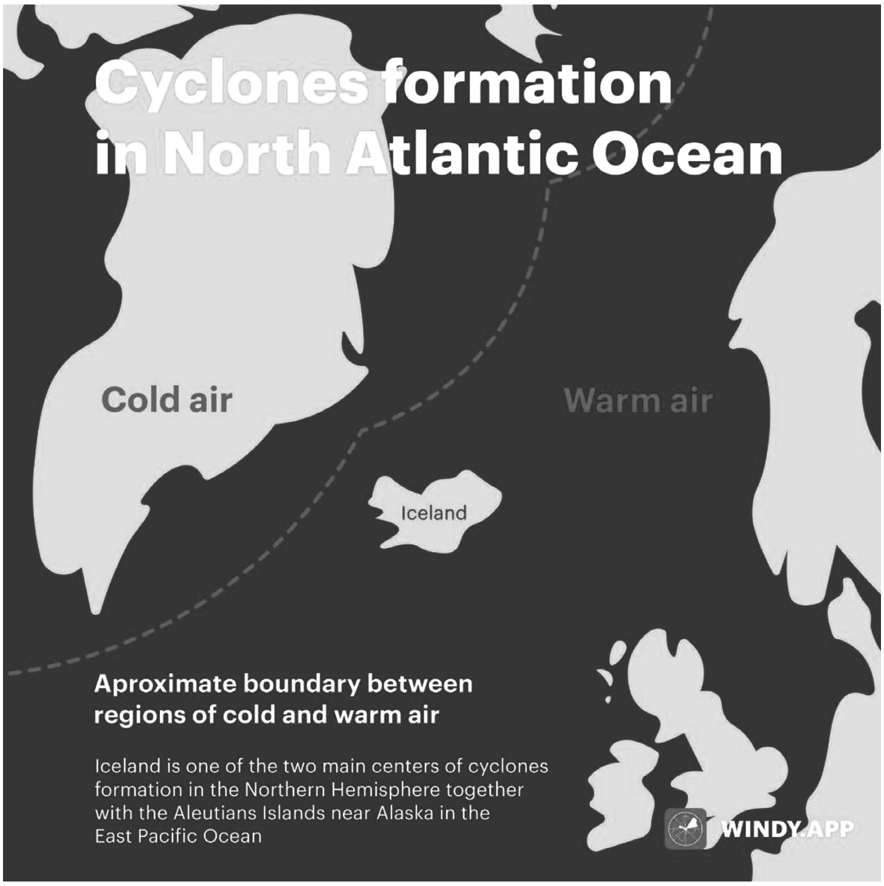

Figure 4.4 : Cyclones formation in North Atlantic Ocean.
[Source : Valeriya Milovanova/Windy.app]

4.3.4 Megascale meteorology — largest or global

Megascale meteorology or megameteorology (as well as largest or global meteorology), as the name suggests, studies weather phenomena on a worldwide scale that last up to a month or more and occur continuously or with a certain periodicity, that is, they go from weather to climate (average weather over months, years, decades, and further down to millions of years).

For example, these are the global winds that blow around the globe. The two main types of global winds are trade winds, which blow all the time from the tropics to the equator, and monsoons, which change direction according to the seasons. It carries air masses of varying temperature and humidity, causing drought and rain. We emphasize again that global winds and other large-scale weather phenomena travel vast distances as they circle the earth (equatorial length is 40.075 km), and time intervals.

This also includes, say, El Niño in South America, which occurs once every five years and disrupts the usual atmospheric and oceanic processes.

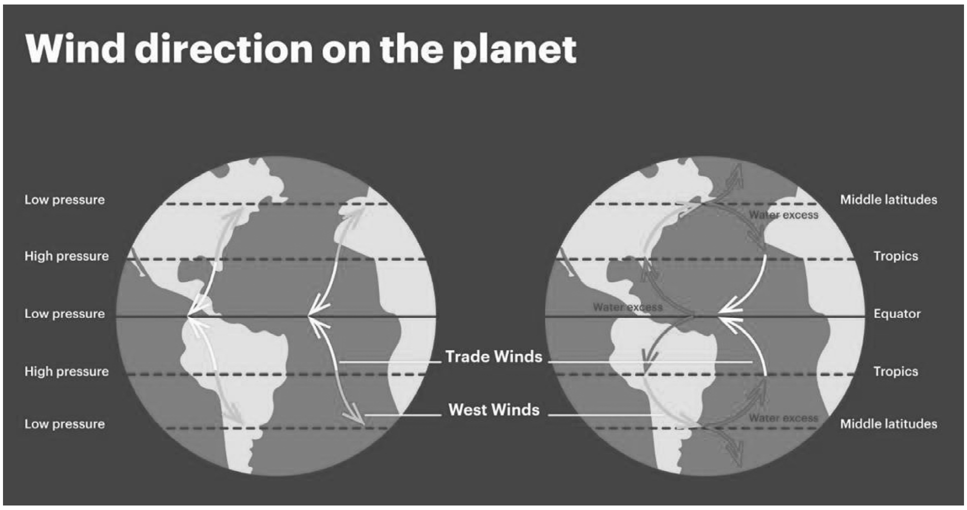

Figure 4.5 : Wind direction on the planet: global winds and west winds.
[Source : Valeriya Milovanova/Windy.app]

4.3.5 Four meteorological scales : comparison table

Meteorology scales
Comparison table

Type	Scale	Distance scale	Time scale	Examples
Microscale meteorology	Small or local	Centimeters to a few kilometers	Less than a day	Soil temperatures in a small area, cloud features, brief thunderstorms, local turbulence, air pollutants
Mesoscale meteorology	Medium or regional	Kilometers to 1,000 kilometer	Days to weeks	Weather fronts, large thunderstorms, squall lines, sea and land breezes, vortexes, and others
Synoptic meteorology	Large or national and continental	100s to 1000s kilometers	Up to a month	High and low-pressure areas, tropical cyclones (hurricanes and typhoons), extratropical cyclones
Global meteorology	Largest or Global	World (40,075 km by equator)	Months and years	Global winds (trade winds and monsoons), El Niño, and others

Figure 4.6 : Meteorlogy scales

4.4 The Elements of Weather and Climate

Weather is nothing more than the different elements it is composed of, as well as the way they interact with each to create different atmospheric conditions or weather events. We first need to identify what the elements are that make up the weather. Eight primary elements/factors drive all weather:

1. Temperature
2. Air (Atmospheric) Pressure
3. Wind (Speed & Direction)
4. Humidity
5. Precipitation
6. Visibility
7. Clouds (Type & Cover)
8. Sunshine Duration

1. Temperature

We all know what temperature is a crucial factor of environment. When discussing the weather, this will probably be one of the first topics that come up. It is because we are so sensitive to temperature and quickly become aware of feeling cold or hot. We know what it feels like, but what exactly is temperature?

What Is Temperature?

Temperature is a measurement of the amount of kinetic energy present in the air, which manifests itself physically through the experience of heat or cold. The scales typically used to measure temperature, is Celsius, Fahrenheit, and Kelvin. The instrument used to measure temperature is called a thermometer.

In more practical terms, it means that the particles in the air move or vibrate at a certain speed, which creates kinetic energy. When the particles start to move/ rotate around faster, temperature increases. When the particles begin to slow down, the temperature also starts to decrease.

Instrument for Measuring Temperature

The thermometer is the instrument used to measure temperature. They come in all shapes and sizes and dates all the way back to 1714. The mercury, bimetal, and digital thermometer are the three most commonly used instruments for measuring ambient temperature.

2. Air Pressure

Air pressure is another essential element of weather, especially when it comes to creating or changing atmospheric conditions. It is also one of the critical variables used to make accurate weather forecasts.

What is Air (Atmospheric) Pressure?

Air Pressure is the result of the pressure created by the weight of the air in the Earth's atmosphere. It is also called a barometric pressure, named after the instrument used to measure air pressure.

Although it may not be visible, air has weight since it is not empty. It is filled with small particles of nitrogen, oxygen, argon, carbon dioxide and a few other gases. The weight of the particles in the air creates pressure due to the gravitational force of the Earth. Since more air is present above the air close to the ground, air pressure is the highest on the planet's surface and decreases as altitude increase.

Instrument for Measuring Air Pressure

The barometer is the instrument used to measure air pressure. Evangelista Torricelli developed the first device in 1643. Like the thermometer, the barometer also comes in different forms. Some examples include mercury, water, aneroid, and digital barometers.

3. Wind (Speed & Direction)

The movement of air (wind) is one of the main driving forces of weather. The majority of major and even extreme weather events like cold & warm fronts, clouds, thunderstorms, and hurricanes are all driven by wind.

What is Wind?

Wind is the large-scale movement of air from an area of high to an area of low pressure in the atmosphere.

The speed and strength of wind are determined by the distance between the lowpressure and high-pressure areas, as well as the difference in air pressure.

Instruments for Measuring Wind Speed and Direction

The anemometer is the instrument used to measure wind speed. Consisting of 3-4 half-cups on arms rotating around a central axis, you can typically find it on top of a weather station or at an elevated position. A wind vane (or weather vane) is the instrument used to measure wind direction. It is a flat-shaped object that spins freely on an axis. Very often in the shape of an arrow or cockerel, you can also find it on top of a weather station or highly elevated objects. It is common to see them on top of roof chimneys, church towers, and even communication towers.

4. Humidity

Humidity is another weather element that cannot be seen but can be felt. It not only plays a big part in weather formation but also directly influence our physical comfort levels.

What is Humidity?

Humidity is the amount of water vapor that is present in the atmosphere at any specific time. Water vapor is nothing more than water in a state of gas (after the liquid has evaporated). Although humidity and its effects can usually be felt, it is normally invisible to the naked eye. Humidity can be challenging to understand and interpret correctly. Then you also have to be able to make a clear distinction between absolute and relative humidity.

Instrument for Measuring Humidity

The hygrometer is the instrument used to measure wind speed. You also find more than one type of this device, like the psychomotor and the resistance hygrometer.

5. Precipitation

There is no argument that water in any of its forms is an absolute necessity for life on Earth to exist. Humans, animals, and plants need water to grow or stay alive, and precipitation is the only way to replenish the dams, rivers, reservoirs, and groundwater on which we rely.

What is Precipitation?

Precipitation is water in all its different states, which formed after condensation turned water vapor into its solid form, which falls to the ground after it becomes too heavy to stay suspended in the air. Precipitation can take the form of rain, snow, hail, or graupel. Precipitation is primarily the result of evaporation and condensation.

Instrument for Measuring Rainfall

A rain gauge is the instrument used to measure rainfall. It is essentially a measured container that captures rain and measures the amount that falls over a set period of time.

6. Visibility

Visibility may seem like a very unlikely element of weather, but is especially important when discussing and measuring weather conditions like fog, mist, freezing drizzle, and smog.

What is Visibility?

Visibility is the measurement of the degree through which an object can be observed over a certain distance. This measurement is crucial when conditions like mist, haze, fog, and freezing drizzle are present, which can severely impede visibility. The importance to be able to measure this element is often underestimated. It is especially applicable in areas where visibility plays a crucial role, like airports and harbors where it can literally be a matter of life or death.

Instrument for Measuring Visibility

Visibility sensors like “forward scatter sensor” are the instruments used to measure visibility. In the past, using your own vision (eyes) to measure the degree to which you can observe an object, was the standard.

7. Clouds (Type & Cover)

It is no secret that clouds are one of the quickest ways to determine current and future weather conditions. Studying them in more detail with scientific equipment is very valuable to make very accurate assessments of present and feature atmospheric conditions.

What are Clouds?

Clouds are water droplets or water in different states (like ice and snow crystals), which formed after water vapor reached condensation level and could no longer remain in gaseous form. Knowing how to identify a certain type of cloud and the weather associated with it, can prove valuable when assessing weather conditions with only visual references.

Instrument for Measuring Clouds

The advanced instruments meteorologists use to study clouds in detail are weather satellites and radars. Satellite and radar images are able to accurately measure cloud density, the amount of moisture, the temperature, and movement of the clouds.

8. Sunshine Duration

The amount of sunshine the Earth receives (which is a characteristic of solar radiation) greatly influence other elements of the weather like ambient temperature, and more indirectly humidity and air pressure.

What is Sunshine Duration?

Sunshine duration is the length of time the Earth's surface is directly exposed to solar radiation. It is also referred to as sunlight hours and measure the amount of exposure over a set period of time (generally in hours per day or year.)

As already stated, sunshine duration influences other weather elements, which can change the whole makeup of the weather conditions. This ability makes it a more powerful and influential factor than you might think.

Instrument for Measuring Sunshine

Sunshine recorders, more specifically Campbell–Stokes recorders, are the instruments used to record sunshine duration. Campbell–Stokes recorders basically consist of a spherical lens that focuses sunlight on a specific type of tape to make its measurement.

4.5 Coriolis force

What is the Coriolis Force?

In any rotating reference frame, such as the Earth, a merry-go-round or a spinning ice skater, an observer sees a new influence on the motion of objects.

A ball thrown between two friends on a merry-go-round will appear to them to take a curved path. They are spinning with the merry-go-round, while the ball moves freely through the air. The force that causes this curvature of motion in the rotating reference frame is the Coriolis force. It always points perpendicular to the object's velocity.

This famous force is most widely associated with large-scale phenomena, especially in meteorology. However, the Coriolis force is named after a French mathematician who worked in a very different field. Gaspard Gustave Coriolis' (1792-1843) most famous paper was entitled "On the equations of relative motion of a system of bodies," and an earlier paper was called "On the principle of kinetic energy in the relative motion in machines." Coriolis is credited with extending the concepts of work and energy to the rotating reference frame and applied his research to machines such as waterwheels.

Once air has been set in motion by the pressure gradient force, it undergoes an apparent deflection from its path, as seen by an observer on the earth. This apparent deflection is called the "Coriolis force" and is a result of the earth's rotation.

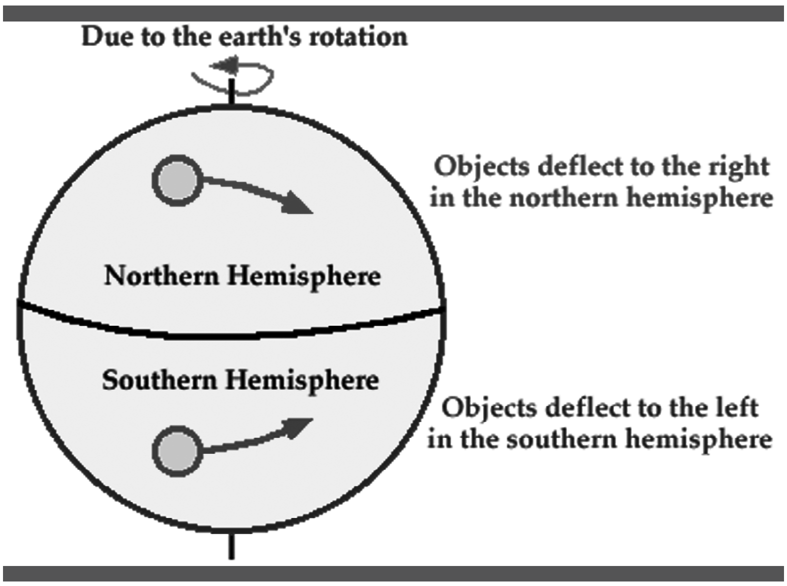

Figure 4.7 : Due to earth rotation

As air moves from high to low pressure in the northern hemisphere, it is deflected to the right by the Coriolis force. In the southern hemisphere, air moving from high to low pressure is deflected to the left by the Coriolis force.

The amount of deflection the air makes is directly related to both the speed at which the air is moving and its latitude. Therefore, slowly blowing winds will be deflected only a small amount, while stronger winds will be deflected more. Likewise, winds blowing closer to the poles will be deflected more than winds at the same speed closer to the equator. The Coriolis force is zero right at the equator.

4.5.1 Characteristics of Coriolis Force

The characteristic features of Coriolis force may be summarized as follows :

1. Coriolis force is not in itself a force rather is an effect of rotational movement of the earth.
2. Coriolis force becomes effective on any object which is in motion (i.e., wind, flying birds, aircrafts, ballistic missiles, long-range artillery fire *etc*.).
3. Coriolis force affects wind direction and not the wind speed as it deflects the wind (and other moving objects) direction from expected path.
4. The magnitude of Coriolis force is determined by wind speed. The higher the wind speed, the greater is the deflection of wind direction due to resultant greater deflective (Coriolis) force.
5. It becomes maximum at the poles due to minimum rotational speed of the earth while it becomes zero at the equator.
6. It always acts at right angles to the horizontally moving air and other moving objects. The net effects is that the horizontal winds are deflected to the right in the northern hemisphere and to the left in the southern hemisphere.

4.5.2 Deflection of Moving Objects

One simple example of the Coriolis force has been observed at least as early as 1651. Italian military officers wrote that in artillery practice their cannon balls always landed to the right of where their calculations predicted. Their observations were correct. The cannon ball was shot over such a long distance that while it was in the air, the Earth rotated underneath it. Since these officers were in Italy, they saw the cannon balls curve to the right (Earth rotates counter clockwise in the northern hemisphere).

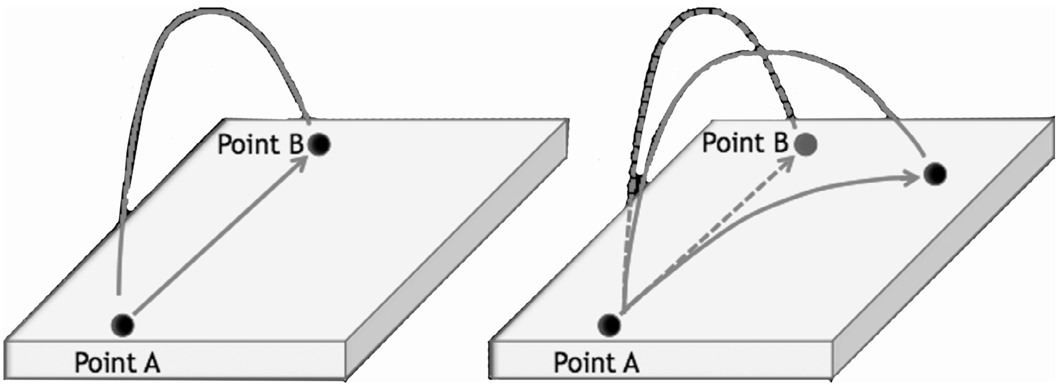

Figure 4.8 : Deflection of moving

Earth is a rotating reference frame. This is why the Coriolis force can be observed acting on a cannon ball (as long as it is shot over a sufficiently large distance). There are countless other examples of the Coriolis force acting on Earth. In fact, it is crucial to creating the conditions on Earth that we take for granted. Some of the major instances of the Coriolis force on Earth are discussed under the "Rotating Earth" section of this website.

4.5.3 Quantifying the Coriolis Force

From a rotating reference frame, any object in motion will be influenced by the Coriolis force. Its strength depends on only a few variables, and the relative direction of their vectors. First of all, the object's linear (tangential) velocity must be considered. Only the component of velocity that is perpendicular to the rotating frame's axis of rotation contributes to the Coriolis force. Angular velocity, then, is also a factor in the equation for the Coriolis force. In particular, one must determine the cross product of linear velocity and angular velocity. The final factor in the Coriolis force is the mass of the object.

$$\mathbf{F_{Coriolis} = -\ 2m\ (\Omega \times v)}$$

The vector equation for the Coriolis force is shown above. The underlined and bolded characters are vectoring whose magnitudes and directions must be considered. As mentioned, the cross product between rotational velocity (omega) and linear velocity (v) multiplies only the vector components that are orthogonal. The result of the cross product is orthogonal to both v and O. Its direction can be determined by the right-hand rule. Take your right hand and orient your index finger, middle finger and thumb as shown below.

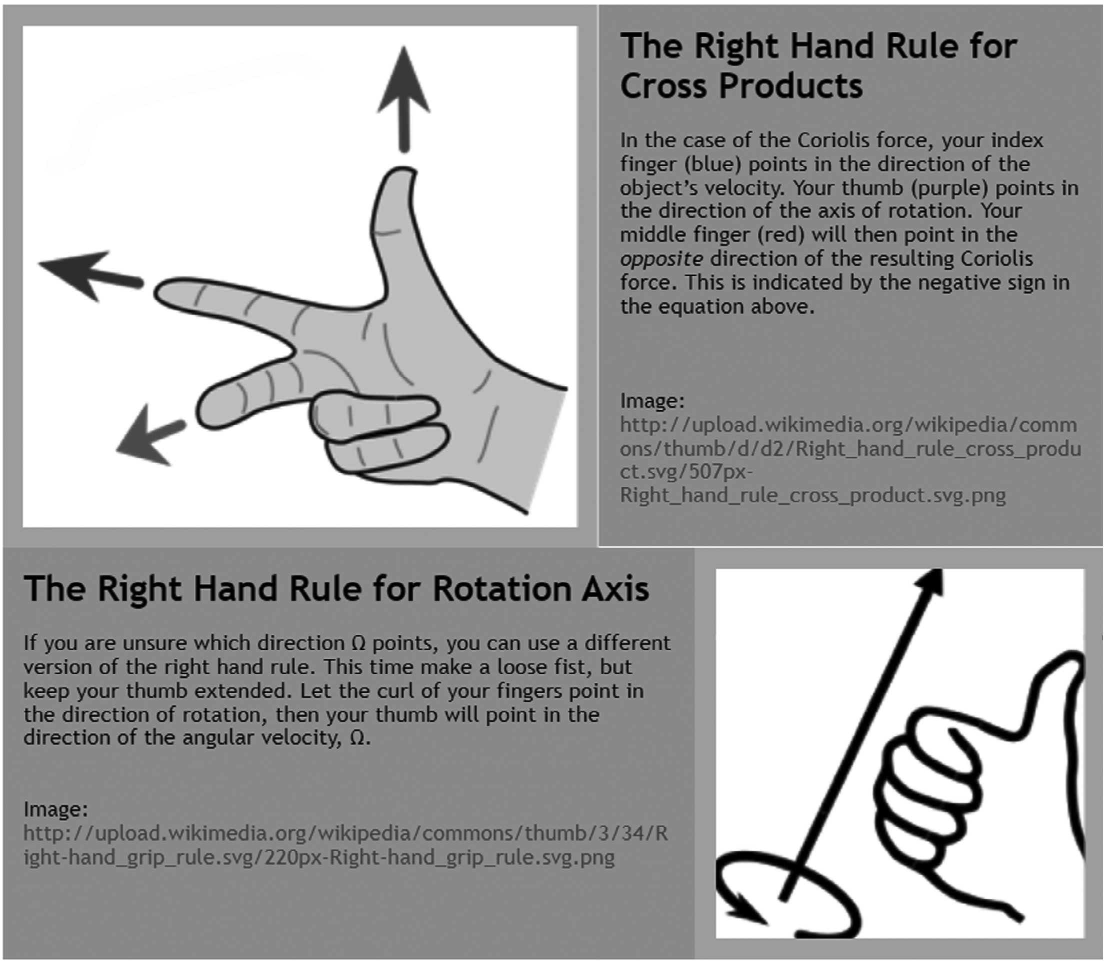

Figure 4.9 : Write hand rule

4.6 Pressure gradient force

The variation of heating (and consequently the variations of pressure) from one locality to another is the initial factor that produces movement of air or wind. The most direct path from high to low pressure is the path along which the pressure is changing most rapidly. The rate of change is called the pressure gradient. Pressure gradient force is the force that moves air from an area of high pressure to an area of low pressure. The velocity of the wind depends upon the pressure gradient. If the pressure gradient is strong, the windspeed is high. If the pressure gradient is weak, the windspeed is light. Figure 4.10 shows that the flow of air is from the area of high pressure to the area of low pressure, but it does not flow straight across the isobars. Instead, the flow is circular around the pressure systems. Pressure gradient force (PGF) causes the air to begin moving from the high-pressure to the low-pressure system. Coriolis (deflective) force and centrifugal force then begin acting on the flow in varying degrees. In this example, frictional force is not a factor.

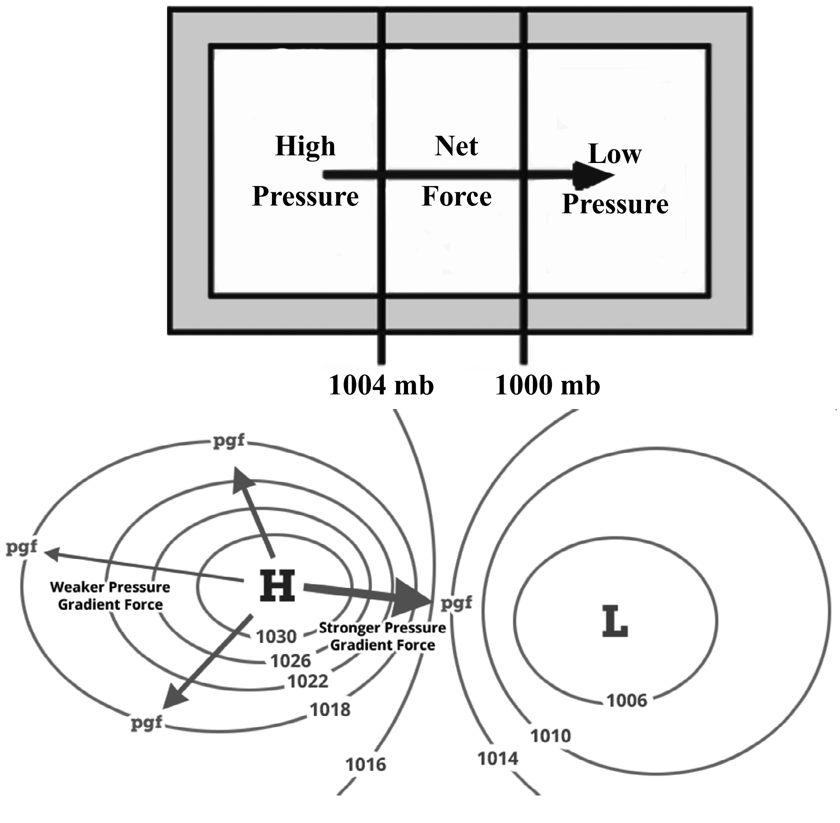

Figure 4.10 : Pressure gradient force

4.7 Frictional Force

Friction is the force that resists motion when the surface of one object comes in contact with the surface of another. The mechanical advantage of a machine is reduced by friction, or in other words, the ratio of output to input is reduced because of friction. An automobile uses one-quarter of its energy on limiting friction. Yet, it is also friction in the tires that allows the car to stay on the road and friction in the clutch that makes it possible to drive. From matches to machines to molecular structures, friction is one of the most significant phenomena in the physical world. In this article, let us discuss frictional force and its different types.

What is frictional force ?

The force generated by two surfaces of two objects when they come in contact and slide against each other is called the force of friction. The factors affecting frictional force include :

- The frictional force is significantly affected by the texture of the surface and the quantity of force that propels them together.
- The force of friction is affected by the position and angle of the object.
- If we place an object flat against another object, then the force of friction is equal to the object's mass.
- If we push an object against the surface of another object, then the amount of the frictional force is increased, which becomes higher than the object's weight.

4.7.1 Calculating Frictional Force

The friction force formula is given by : $F = \mu N$

Suppose we consider a wood block weighing 2 kg lying on a table to be moved from rest. We consider the static friction coefficient in this case, which is 00.5 in the case of wood.

The normal force can be calculated with the given details, $N = 2\ \text{kg} \times 9.8\ \text{N/kg} = 19.6\ \text{N}$

As we now have the values of static friction coefficient and normal force, the frictional force can be calculated as follows :

$$F = 0.5 \times 19.6\ \text{N} = 9.8\ \text{N}$$

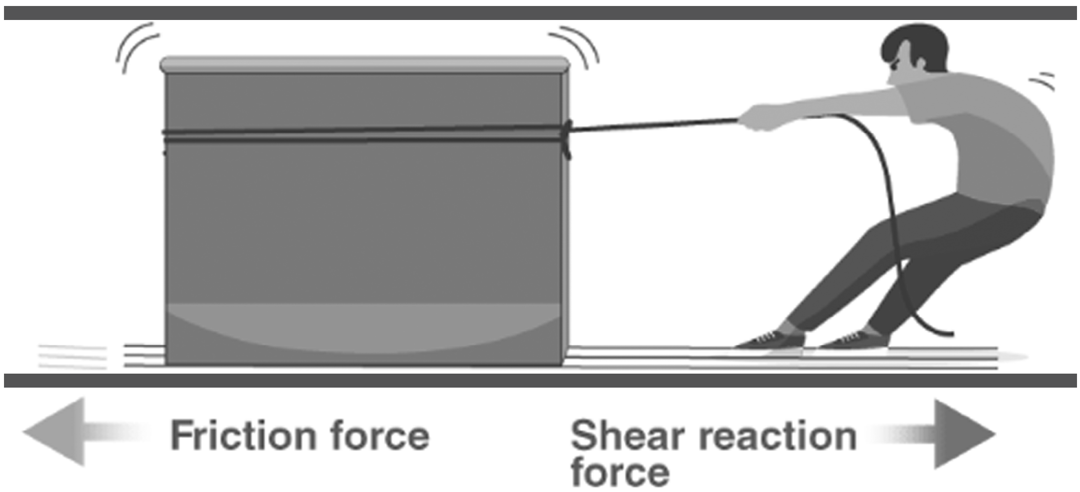

Figure 4.11 : Calculating Frictional Force

4.8 Indian Monsoon

- The climate in India is hot monsoonal, as is the climate in South and Southeast Asia.
- Out of four seasons prevailing in the Indian subcontinent, monsoon seasons acquire two. They are
  - The Southwest Monsoon Season
  - The North-East Monsoon Season

4.8.1 Onset of the Monsoon

- When the sun shines vertically over the Tropic of Cancer in April and May, the large landmass to the north of the Indian Ocean becomes extremely hot.
- In the north western part of the subcontinent, this results in the formation of an intense low-pressure system.
- The low-pressure cell attracts southeast trades across the Equator because the pressure in the Indian Ocean to the south of the landmass is high due to the slow heating of water.

- These conditions aid in the ITCZ northward shift in position.
- After crossing the Equator, the southwest monsoon can be seen as a continuation of the southeast trades deflected towards the Indian subcontinent.
- Between 40°E and 60°E longitudes, these winds cross the Equator.
- The southwest monsoon arrives on the Kerala coast on June 1st and moves quickly through Mumbai and Kolkata between June 10th and 13th.
- The southwest monsoon engulfs the entire subcontinent by mid-July.

Intertropical Convergence Zone (ITCZ)

The ITCZ is a low-pressure belt that determines precipitation in the tropics by its northward and southward movements along the equator.

4.8.2 The Southwest Monsoon Season

- The Rainy Season is from June to September.
- As a result of the rapid rise in temperature over the north western plains in May, the low-pressure conditions there have become even more intense.
- They are powerful enough to attract the Southern Hemisphere trade winds coming from the Indian Ocean by early June.
- These southeast trade winds cross the equator and enter the Bay of Bengal and the Arabian Sea, only to become entangled in the air circulation over India.
- They bring a lot of moisture with them as they pass over the equatorial warm currents.
- They travel in a south-westerly direction after crossing the equator. Southwest monsoons are named after this.

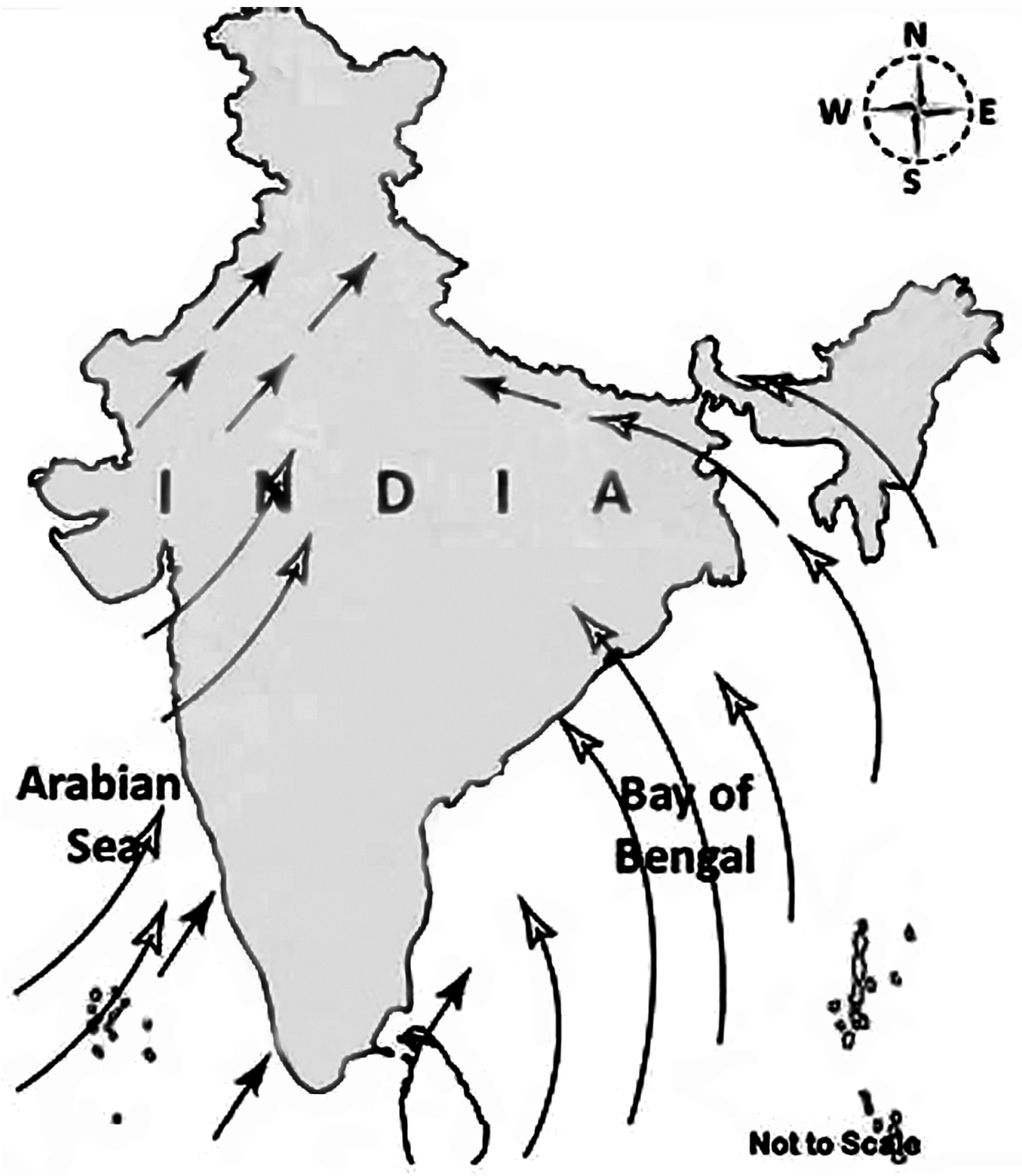

Figure 4.12 : The direction of Southwest Monsoon in India

4.8.3 Southwest Monsoon Bursts

- The rain begins abruptly during the southwest monsoon season.
- The first rain has the effect of significantly lowering the temperature.

- The “break” or “burst” of the monsoons refers to the sudden onset of moisture-laden winds accompanied by violent thunder and lightning.
- In the coastal areas of Kerala, Karnataka, Goa, and Maharashtra, the monsoon may arrive in the first week of June, while in the interior, it may arrive in the first week of July.
- Between mid-June and mid-July, the daytime temperature drops by 5°C to 8°C.
- The relief and thermal low pressure over northwest India modify the south westerly direction of these winds as they approach the land.
- The monsoon is divided into two branches as it approaches the landmass:
- The Arabian Sea branches
- The Bay of Bengal branch

4.8.4 North-East Monsoon

- The northeast monsoon enters India from the northeast.
- The wind blows from the sea to the land in this type of monsoon.
- The moisture from the Indian Ocean is carried by the monsoon winds.
- The northeast monsoon is limited to south India, bringing rain to Tamil Nadu, Puducherry, Karaikal, Yanam, Andhra Pradesh, Kerala, Mahe, and south interior Karnataka from October to December.
- Low-pressure systems, depressions, and cyclones cause the associated rainfall, also known as the winter monsoon.
- This is Tamil Nadu’s main rainy season, with the state receiving 48% (447.4 mm) of its annual rainfall during these three months.

Figure 4.13 : The direction of North-East Monsoon in India

4.8.5 Monsoon winds of the Arabian Sea

The three branches of the monsoon winds that originate over the Arabian Sea are as follows:

- The first stream hits India's west coast, dumping over 250 cm of rain on the country.
- It strikes the Western Ghats perpendicularly, resulting in abundant Orographic Rainfall [400 to 500 cm annual rainfall on the windward side].
- On the leeward side of the crest, rainfall is reduced to about 30-50 cm.

- On the immediate leeward side of the Western Ghats, there is a narrow belt of severe aridity.
- However, once it has passed, the air begins to rise again, and rainfall amounts increase further east.
- The second stream flows through the Narmada—Tapi troughs (narrow rift valley) before reaching central India.
- Due to the lack of a major orographic obstacle across the rift, it does not produce much rain near the coast.
- This stream brings rain to some parts of central India (Ex: Nagpur).
- The third stream runs parallel to the Aravali Range and does not produce much rain. As a result, Rajasthan is primarily a desert state.
- On the south-eastern edge of the Aravali Range, however, there is some orographic effect.
- Mt. Abu receives about 170 cm of rain, whereas the surrounding plains receive only 60 to 80 cm.

4.9 Koppen's Classification of Climatic Regions of India

- Koppen's Classification of Climatic Regions of India is an empirical classification based on mean annual and mean monthly temperature and precipitation data.
- Koppen identified a close relationship between the distribution of vegetation and climate.
- He selected certain values of temperature and precipitation and related them to the distribution of vegetation and used these values for classifying the climates.
- Koppen recognized five major climatic groups, four of them are based on temperature and one on precipitation.

The capital letters :

1. A, C, D and E delineate humid climates and

2. B dry climates.

The climatic groups are subdivided into types, designated by small letters, based on seasonality of precipitation and temperature characteristics.

The seasons of dryness are indicated by the small letters: f, m, w and s, were

1. f – no dry season,

2. m – monsoon climate,

3. w – winter dry season and

4. s – summer dry season.

- The above mentioned major climatic types are further subdivided depending upon the seasonal distribution of rainfall or degree of dryness or cold.

a : hot summer, average temperature of the warmest month over 22°C

c : cool summer, average temperature of the warmest month under 22°C

f : no dry season

w : dry season in winter

s : dry season in summer

g : Ganges type of annual march of temperature; hottest month comes before the solstice and the summer rainy season.

h : average annual temperature under 18°C m (monsoon) : short dry season.

- The capital letters S and W are employed to designate the two subdivisions of dry climate :

  1. Semi-arid or Steppe (S) and

  2. Arid or desert (W).

- Capital letters T and F are similarly used to designate the two subdivisions of polar climate

  1. Tundra (T) and

  2. Icecap (F).

Table 4.1 : Climatic Groups According to Koeppen

Group	Characteristics
A-Tropical	Average temperature of the coldest month is 18° C or higher
B-Dry Climates	Potential evaporation esceeds precipitation
C-Warm Temperature	The average temperature of the coldest month of the (Mid-latitude) climates years is higher than minus 3°C but below 18°C
D-Cold Snow Forest Climates	The average temperature of the coldest month is minus 3° C or below
E-Cold Climates	Average temperature for all months is below 10°C
H-High Land	Cold due to elevation

Table 4.2 : Climatic Types According to Koeppen

Group	Type	Letter Code	Characteristics
A-Tropical Humid Climate	Tropical wet	Af	No dry season
	Tropical monsoon	Am	Monsoonal, short season
	Tropical wet and dry	Aw	Winter dry season
B-Dry Climate	Subtropical steppe	BSh	Low latitude semi arid or dry
	Subtropical desert	BWh	Low latitude arid or dry
	Mid-latitude steppe	BSk	Mid-latitude semi arid or dry
	Mid-latitude desert	BWk	Mid-latitude arid or dry
C-Warm temperature (Mid-latitude) Climates	Humid subtropical	Cfa	No Dry season, warm summer
	Mediterrameam	Cs	Dry hot summer
	Mrine west coast	Cfb	No dry season, warm and cold summer
D-Cold Snow-forest Climates	Humid continental	Df	No dry season, severe winter
	Subarctic	Dw	Winter dry and very severe
E-Cold Climates	Tundra	ET	No true summer
	Polar ice cap	EF	Perennial ice
H-Highland	Highland	H	Highland with snow cover

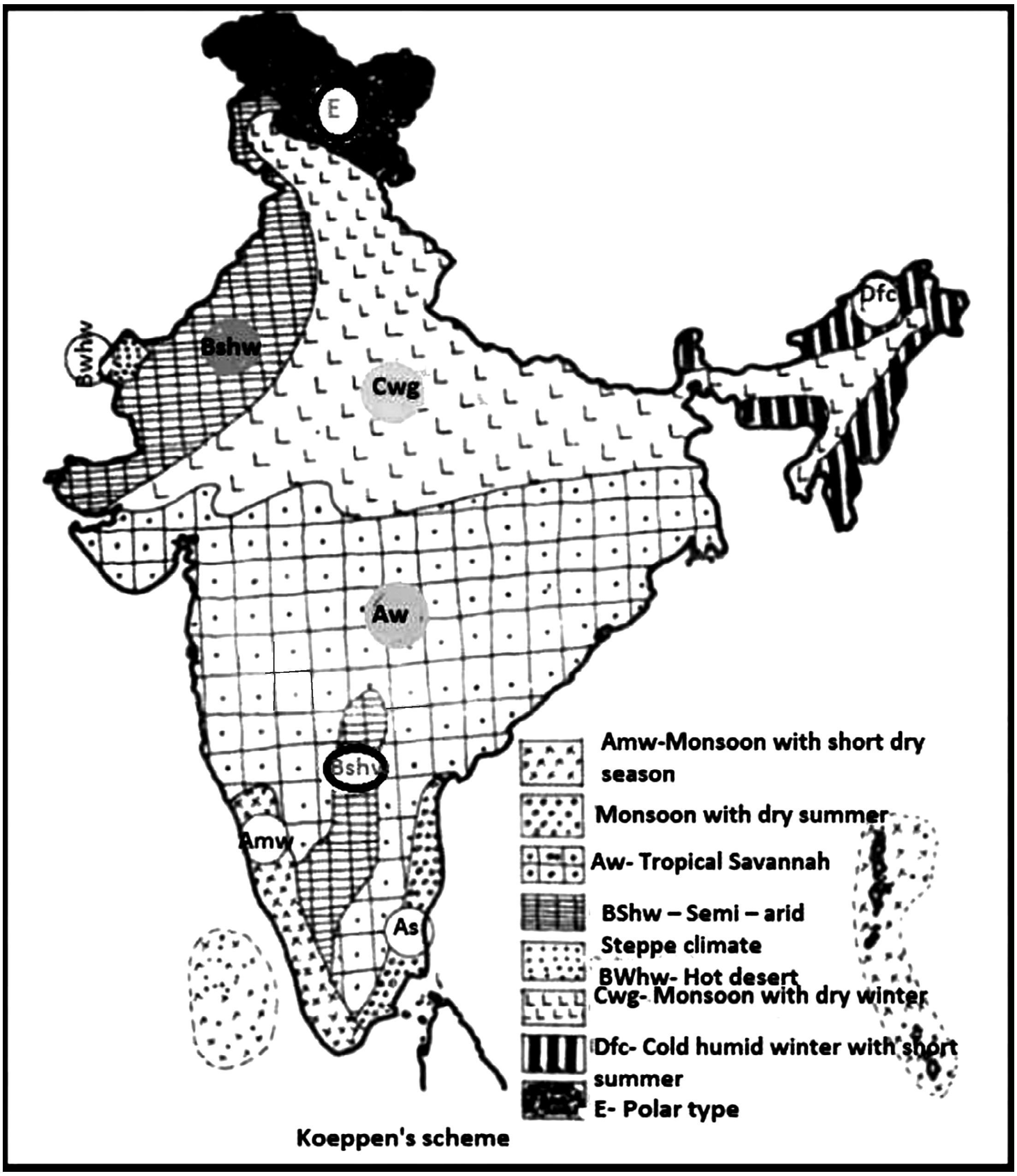

Figure 4.14 : Koeppen's classification of Indian Climate

Table 4.3 : Koeppen's Scheme – Climatic Regions of India

Climate type	Region	Annual rainfall
Amw (Monsoon type with short dry winter season)	Western coastal region, south of Mumbai	over 300 cm
As (Monsoon type with dry season in high sun period)	Coromandel coast = Coastal Tamil Nadu and adjoining areas of Andhra Pradesh	75 – 100 cm [wet winters, dry summers]
Aw (Tropical Savanah type)	Most parts of the peninsular plateau barring Coromandel and Malabar coastal strips	75 cm
BShw (Semi-arid Steppe type)	Some rain shadow areas of Western Ghats, large part of Rajasthan and contiguous areas of Haryana and Gujarat	12 to 25 cm
BWhw (Hot desert type)	Most of western Rajasthan	less than 12 cm
Cwg (Monsoon type with dry winters)	Most parts of the Ganga Plain, eastern Rajasthan, Assam and in Malwa Plateau	100 – 200 cm
Dfc (Cold, Humid winters type with shorter summer)	Sikkim, Arunachal Pradesh and parts of Assam	~200 cm
Et (Tundra Type)	Mountain areas of Uttarakhand The average temperature varies from 0 to 10°C	Rainfall varies from year to year.
Et (Tundra Type)	Higher areas of Jammu & Kashmir and Himachal Pradesh in which the temperature of the warmest month varies from 0° to 10°C	Precipitation occurs in the form of snow

4.9.1 Advantages

- It has precise definitions that can be applied easily to standardize data that are available for
- locations throughout the world.
- reasonable correlation globally with major vegetation regions
- It requires a minimum amount of calculation.
- It is widely used in educational circles throughout the world.

4.9.2 Limitations

- It utilizes, for example, only the data or mean monthly temperature and precipitation.
- There is not provision for variations in the strength or constancy of winds, temperature extremes,
- precipitation intensity and range, amount of cloud cover, or the net radiation balance.
- more precise and varied factors are not included.

4.10 Summary

The fundamentals of climatology has been discussed vividly in this unit. Scale of meteorology, elements of weather and climate, monsoon and climatic classification of India have been explained in this portion. The learners will gather the knowledge about the conceptional base of weather and climate which will help to understand climate change.

4.11 Questions/Self-Assessment questions

1. Make a comparison on different scale of meteorology.
2. What is Coriolis force? How does it works?
3. What is pressure gradient force
4. Describe the north-east monsoon and southern burst of Indian monsoon.

5. Demonstrate koppen's classification of climatic regions of India
6. What are the advantages of koppen's classification?
7. What is ITCZ?

4.12 Suggested Readings

1. Global climate change. Ipswich, Mass., H.W. Wilson, a division of EBSCO Information Services
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4. Balasubramanian, A.. (2017). ELEMENTS OF CLIMATE AND WEATHER. 10.13140/RG.2.2.30133.58085.
5. http://www.jiwaji.edu/pdf/ecourse/tourism/elements%20of%20weather%20and%20climate.pdf
6. https://windy.app/blog/scales-of-meteorology.html
7. https://www.imdpune.gov.in/training/training%20notes/Climatology-IMTC.pdf
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9. https://www.pmfias.com/climatic-regions-of-india-stamps-koeppens-classification/
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15. Climatology, Lal. D.S. Sharda Pustak Bhawan (1 January 2011)

Unit - 5 ❑ Climate Change

Structure

5.1 Objectives

By successfully completing this unit, you will be able to :

- know about climate change and its feedback and response's

- know about the National Action Plan on Climate Change (NAPCC)
- Understand the green building why it called
- Understand GRIHA rating procedures
- visualize the time frame of COPs

5.2 Introduction

Recognition of climate change as a significant global environmental change has a recent origin. International effort to address climate change formally began two decades ago with the adaptation of the United Nation Framework Convention on Climate Change (UNFCCC) in 1992. Not with standing the ultimate objectives of the convention to stabilize the green houses gases concentration in the atmosphere, scientific assessment has continued to warn about plausible futures with varying degrees of climate change (IPCC, 2001). Multilateral negotiation till date have paid greater attention to the control of greenhouse gas emission that cause the climate change. The prominence of emission mitigation in global negotiation obscured the importance of the vulnerability of natural and human system to climate changes and their adaption to such changes. And of the need for strategies to adopt to the chaining climate (IPCC, 2001).

The complexity of the climate change regime arises from multiple asymmetries. An important asymmetry is the separation between the historical sources of emissions and those who are vulnerable to its effects, while most of the anthropogenic greenhouse gas emission are contributed by economic activities in affluent nations, the burden of climate change impacts on poorer nations is disproportionately high. The risk of the poorer nations are greater due to dual effects; first is the uneven natural distribution of impacts that causes greater damage in tropical regions, second is the higher vulnerability of poorer nations due to their lower capacity and means to adopt. The fact that the impacts are inadequately understood adds further to the existing risk.

Realization that climate is far from being constant came only during the 1840s, when indisputable evidence of former Ice Ages was obtained. Studies of past climate began with a few individuals in the 1920s and gained momentum in the 1950s. Instrumental records for most parts of the world span only the past 100 to 150 years, and are typically assembled at monthly, seasonal or annual time resolution. However, proxy indicators from tree rings, pollen in bog and lake sediments, ice core records of physical and chemical parameters, and ocean foraminifera in sediments provide a wealth of paleoclimatic data. Tree rings and ice cores can give seasonal or annual records. Peat bog and ocean sediments may provide records with 100 to 1000-year time resolution.

In any study of climate variability and change, one must pay careful attention to possible artifacts in the records. For instrumental records, these include changes in instrumentation (*e.g.*, rain gauge types), observational practices, station location, or the surroundings of the instrumental site, or even errors in transcribed data. Proxy records may suffer from errors in dating or interpretation. Even when climate signals are real, it may be difficult to ascribe them to unique causes owing to the complexity of the climate system, a system which is characterized by myriad interactions between its various components on a suite of spatial and temporal scales.

5.3 Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) offers a different definition that can help to resolve some of these problems. They define climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the atmosphere and which is in addition to natural climate variability observed over comparable timescales'. This definition is useful in that it makes a clear distinction between natural processes and anthropogenic influences. The remainder of this chapter will view climate change in this context. Variability, in turn, will be viewed as associated with natural processes.

5.3.1 General Considerations

In this final chapter we examine climate variability and change, climate forcing factors, feedbacks and projected future states of the climate system. In many parts of the world, the climate has varied sufficiently within the past few thousand years to affect patterns of agriculture and settlement. As will become clear, the evidence is now overwhelming that human activities have begun to influence climate.

Realization that climate is far from being constant came only during the 1840s, when indisputable evidence of former Ice Ages was obtained. Studies of past climate began with a few individuals in the 1920s and gained momentum in the 1950s. Instrumental records for most parts of the world span only the past 100 to 150 years, and are typically assembled at monthly, seasonal or annual time resolution. However, proxy indicators from tree rings, pollen in bog and lake sediments, ice core records of physical and chemical parameters, and ocean foraminifera in sediments provide a wealth of paleoclimatic data. Tree rings and ice cores can give seasonal or annual records. Peat bog and ocean sediments may provide records with 100 to 1000-year time resolution.

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What is the distinction between climate variability and change? Climate variability, as defined by the Intergovernmental Panel on Climate Change (IPCC), refers to fluctuations in the mean state and other statistics of climate elements on all spatial and temporal scales beyond those of individual weather events. Variability can be associated with either natural internal processes within the climate system, or with variations in natural or anthropogenic climate forcing. Climate change, by contrast, is viewed by the IPCC as a statistically significant variation in the mean state of the climate or in its variability persisting over an extended period, typically decades or longer. Climate change may be due to natural internal processes, natural external forcings, or persistent anthropogenic-induced changes in atmospheric composition or land use.

The student may be excused if the distinction seems fuzzy. A given climate record, whether from instrumental or from proxy sources, may exhibit a suite of behaviors. It may document a rapid shift from one mean state to another (B), a gradual trend, followed by a new mean state (C) or a change in the variance with no change in the mean over the period of record (D). Even within a fairly stable mean state, there can be fluctuations about that state that are quasiperiodic (B) or non-periodic (C). In turn, a record might be characterized only by long periodic oscillation (A). Given that climate variability as viewed by the IPCC includes fluctuations on all spatial and temporal scales beyond synoptic weather events, one could legitimately view all of the behaviors in the figure as expressions of variability. On the other hand, while one can correctly say (for example) that the major glacial and interglacial cycles of the Pleistocene are expressions of climate variability within the past two million years, it is also appropriate to consider the evolution from full glacial to interglacial conditions as an expression of climate change. Similarly, while we usually view the global temperature rise over the past 100 years as climate change, reserving the term variability for embedded shorter timescale features, the century long warming could also be viewed as an aspect of climate variability over the past 1000 years. The distinction between variability and change is hence dependent on the time frame over which one considers the climate statistics.

The United Nations Framework Convention on Climate Change (UNFCCC) offers a different definition that can help to resolve some of these problems. They define climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the atmosphere and which is in addition to natural climate variability observed over comparable timescales'. This definition is useful in that it makes a clear distinction between natural processes and anthropogenic influences. The remainder of this chapter will view climate change in this context. Variability, in turn, will be viewed as associated with natural processes.

5.3.2 Climate Forcing, Feedback and Response

The most fundamental measure of the earth's climate state is the global mean, annually averaged surface air temperature. Year-to-year and even decadal-scale variations in this value can occur due to processes purely internal to the climate system. The warm phase of ENSO, for example, may be viewed as an internal process in which heat in the ocean reservoir (*i.e.*, heat already within the climate system) is transferred to the atmosphere, expressed as a rise in global mean surface temperature. When considering timescales of decades or longer, thinking must turn to climate forcings and attendant feedbacks. Forcing factors represent imposed perturbations to the global system, and are defined as positive when they induce an increase in global mean surface temperature, and negative when they induce a decrease. Forcing factors may in turn be of natural or anthropogenic origin. The magnitude of the global temperature response to forcing depends on the feedbacks. Positive feedbacks amplify the temperature change while negative feedbacks dampen the change.

1. Climate forcing

Many different types of climate forcing can be identified. Key forcings are associated with the following processes :

Plate Tectonics : On geological timescales, plate tectonics have resulted in great changes in continental positions and sizes, the configuration of ocean basins and (through associated phases in volcanic activity) atmospheric composition. While there is little doubt that such changes altered the globally averaged surface albedo and greenhouse gas concentrations, plate movements have also altered the size and location of mountain ranges and plateaus. As a result, the global circulation of the atmosphere and the pattern of ocean circulation were modified. In 1912, Alfred Wegener proposed continental drift as a major determinant of climates and biota, but this idea remained controversial until the motion of crustal plates was identified in the 1960s. Alterations in continental location have contributed substantially to major Ice Ages of the distant past (such as the Permo-Carboniferous glaciation of Gondwanaland) as well as to intervals with extensive arid (Permo-Triassic) or humid (coal deposits) environments during other geological periods. Over the past few million years, the uplift of the Tibetan Plateau and the Himalayan ranges has caused the onset, or intensification, of desert conditions in western China and Central Asia.

Astronomical periodicities : The earth's orbit around the sun is subject to long-term variations, leading to changes in the seasonal and spatial distribution of solar radiation incident to the surface. These are known as Milankovich forcings after the astronomer Milutan Milankovich, whose careful calculations of their effects built upon the work of nineteenth-century astronomers and geologists. There are three principal effects: the eccentricity (or str*etc*h) of the orbit influencing the strength of the contrast in solar radiation received at perihelion (closest to sun) and aphelion (furthest from sun), with periods of approximately 95,000 years and 410,000 years; the tilt of the earth's axis (approximately 41,000 years) influencing the strength of the seasons; and a wobble in the earth's axis of rotation, which causes seasonal changes in the timing of perihelion and aphelion. This precession effect, with a period of about 21,000 years. Astronomical periodicities are associated with global temperature fluctuations of ± 2-5°C per 10,000 years. The timing of orbital forcing is clearly represented in glacial-interglacial fluctuations with the last four major glacial cycles spanning roughly 100,000 years (or 100 ka). The astronomical theory of glacial cycles became widely accepted in the 1970s after Hays, Imbrie and Shackleton provided convincing evidence from ocean core records.

Solar variability : The sun is a variable star. The approximately 11-year solar (sunspot) cycle (and 22-year magnetic field cycle) are well known. The 11-year sunspot cycle is associated with ±1W m^{-2} fluctuations in solar irradiance (*i.e.*, a departure from the solar constant; in terms of radiation receipts globally averaged over the top of the atmosphere, the effective value is only 0.25W m^{-2}). Effects on ultraviolet radiation are proportionally larger in terms of percent change. There is also evidence for longer-term variations. Intervals when sunspot and solar flare activity were much reduced (especially the Maunder Minimum of AD 1645-1715) may have been associated with global temperature decreases of about 0.5°C. Solar variability also seems to have played a role in decadal-scale variations of global temperature until the latter part of the twentieth century, when anthropogenic effects became dominant. Turning to the distant past, it is known that solar irradiance three billion years ago (during the Archean) was about 80 percent of the modern value. Interestingly, the effect of this faint early sun was offset, most likely, by a concentration of carbon dioxide that was perhaps 100 times higher than now, and perhaps also by the effects of a largely water-covered earth (meaning lots of water vapor in the atmosphere).

Volcanic eruptions. Major individual explosive eruptions inject dust and sulfur gases (especially sulfur dioxide) into the stratosphere, the latter forming sulfuric acid droplets.

Equatorial eruption plumes spread into both hemispheres, whereas plumes from eruptions in mid-to high latitudes are confined to that hemisphere. Observational evidence from the past 100 years demonstrates that major eruptions can be associated with global averaged cooling of several tenths of a degree C in the year following the event and much larger changes on a regional to hemispheric basis. The cooling is primarily from the sulfuric acid droplets which reflect solar radiation. Dust also causes surface cooling by absorbing solar radiation in the stratosphere, but compared to the sulfuric acid these effects are short-lived (weeks to months) Stratospheric aerosols may also cause brilliant sunsets. The most recent major volcanic eruption with significant climate impacts was Mt. Pinatubo in 1991.

Human-induced changes in atmospheric composition and land cover : The effect of greenhouse gases such as carbon dioxide and methane on the radiation budget has already been introduced. The observed buildup of these gases since the dawn of the industrial age represents a positive forcing. Human activities have also led to a buildup of tropospheric aerosols, which induce a partly compensating cooling. Changes in land use and land cover have also led to a small increase in surface albedo that promotes cooling.

While the common feature of all of these forcings is that they influence aspects of the earth's radiation budget, they are obviously distinguished in large part by the timescales at which they operate. In terms of inducing global temperature change over the past 100 years, as well as changes projected through the twenty-first century, the effects of plate tectonics (operating on timescales of millions of years) and Milankovich forcings (operating on timescales of tens of thousands of years) are irrelevant. Note also that while Milankovich forcings are associated with very significant impacts on the seasonal and spatial distribution of solar radiation incident on the surface, impacts on incident radiation when globally averaged through the annual cycle are quite small. For example, while a decrease in obliquity means less summer radiation in the Northern Hemisphere summer, it means more in the Southern Hemisphere winter, with these seasonal effects largely canceling out.

Milankovich forcings hence contrast fundamentally with the effects of changing solar irradiance, volcanic eruptions, or human-induced changes in atmospheric greenhouse gas concentrations and surface albedo, all of which, considered in terms of their immediate effect, have a globally and annually averaged impact on the radiation balance at the top of the atmosphere. Because of this property, they are termed radiative forcings. For example, an increase in solar output will lead to more radiation incident to the top of the earth's atmosphere, irrespective of latitude or season. The immediate effect will be a globally averaged radiation imbalance at the top of the atmosphere (more energy coming in than going out), leading to a rise in temperature that would eventually bring the earth/atmosphere system into a new radiative equilibrium. Similarly, the immediate response to increasing the concentration of greenhouse gases will be a globally averaged decrease in longwave emission to space, a radiation imbalance promoting warming, also eventually leading to a new radiative balance (provided that the forcing remains constant).

Global climate change (change due to human influences by our adopted conventions) is best viewed in the context of global radiative forcing. In the IPCC framework adopted here, radiative forcing specifically refers to the amount by which a factor alters the globally and annually averaged radiation balance at the top of the atmosphere, expressed in units of W m^{-2}, evaluated as forcing relative to the year 1750, the start of the Industrial Revolution. In 2005, there was an estimated radiative forcing from human activities of 1.6W m^{-2}.

2. Climate feedbacks

Building on the framework of radiative forcing, consider further the change in global average surface temperature resulting from increasing the atmospheric concentration of carbon dioxide. As just discussed, because of the imposed perturbation, more of the longwave radiation emitted upward from the surface is absorbed by the atmosphere, and directed back towards the surface. The result is a radiation imbalance at the top of the atmosphere - net solar radiation entering the top of the atmosphere exceeds the longwave loss to space. The climate forcing from adding carbon dioxide is hence positive. Now consider the feedbacks. The most important of these is the water vapor feedback. Warming results in more evaporation, and a warmer atmosphere can carry more water vapor. However, water vapor is also a greenhouse gas, so it causes further warming. Some of the earth's snow cover and sea ice will melt, reducing the earth's surface albedo, also causing further warming. These are examples of positive feedbacks, as they amplify the global surface temperature change induced by the climate forcing. If the carbon dioxide concentration in the atmosphere were lowered, thereby imposing a negative climate forcing, the positive feedbacks would foster further cooling.

A fascinating aspect of the global climate system is that positive feedbacks dominate. For example, one of the responses to increasing greenhouse gases could be an increase in cloud cover, which through increasing the planetary albedo would represent a negative feedback. However, this and other potential negative feedbacks would only appear to be capable of slowing the rate of warming, not reversing it.

While climate feedbacks can be either positive or negative, they can also be broadly differentiated regarding how quickly they operate. In the framework of global radiative forcing appropriate to understanding human-induced global climate change, it is the fast feedbacks which are relevant. The most important are changes in water vapor and albedo (mentioned above). Both can operate over timescales of days and even less. Cloud cover can also change very quickly (hours). Examples of slow feedbacks are changes in the extent of continental ice sheets (influencing planetary albedo) and greenhouse gases during the Pleistocene in response to Milankovich periodicities. Records from ice cores show that these glacial-interglacial cycles were nearly coincident with fluctuations in both atmospheric carbon dioxide (+50 ppm) and methane (+150 ppb). The nature of these trace gas feedbacks remains incompletely resolved. Potential mechanisms include changes in ocean chemistry, increased plankton growth acting to sequester carbon dioxide, suppression of air-sea gas exchange by sea ice, changes in ocean temperature that affect the solubility of carbon dioxide, and altered ocean circulation. Most likely a suite of processes worked in concert. Negative (positive) excursions in greenhouse gas concentrations are associated with cold (warm) intervals.

3. Climate Response

How much does the global mean surface temperature change in response to a radiative forcing of a given magnitude? How long does it take for the change to occur? These are among the most important, pressing questions in climate change science.

The first question deals with the issue of equilibrium climate sensitivity. In the IPCC framework, equilibrium climate sensitivity is the equilibrium change in annual mean global averaged surface air temperature following a doubling of the atmospheric equivalent carbon dioxide. Doubling the carbon dioxide concentration equates to a radiative forcing (top of atmosphere radiation imbalance) of about 4W m^{-2}. In response to this doubling the surface and atmosphere would warm up. Eventually, radiative balance would be restored again with a new and higher surface temperature. Estimates of equilibrium climate sensitivity obtained from the current generation of global climate models range from 2-4.5°C, with a best estimate of 3.0°C. The uncertainly lies largely in the spread of model estimates of the climate feedbacks, particularly in the cloud feedbacks. Cloud feedbacks are complex and hard to model. Negative feedbacks may operate when increased global heating leads to greater evaporation and greater amounts of high-altitude cloud cover, which reflect more incoming solar radiation. However, other types of clouds, and clouds in the polar regions, can induce surface warming

Expressed in a more convenient fashion, the best estimate of 3°C for carbon dioxide doubling equates to 0.75°C global mean surface temperature increase per W m^{-2} of forcing. It is stressed that the climate simulations used to obtain these sensitivity numbers only deal with the fast feedbacks. If there were no feedbacks present in the climate system, the climate sensitivity would be only about 0.30°C per W m^{-2}. While equilibrium climate sensitivity in the IPCC framework is based on a doubling of atmospheric equivalent carbon dioxide, it appears that the equilibrium temperature response to any radiative forcing is roughly the same. This is an important concept, since it means that to a first approximation, one can linearly add different forcings to obtain a net value from which an equilibrium temperature change can be estimated.

It also appears that most of the equilibrium temperature response to a radiative forcing with the fast feedbacks at work occurs over a time span of 30 to 50 years. Most of the time lag is due to the large thermal inertia of the oceans. The basic issue is that the oceans can absorb and store a great deal of heat without a large rise in the surface (radiating) temperature. Consider what is happening in response to the current radiative forcing from human activities of 1.6W m^{-2}. Using the equilibrium climate sensitivity of 0.75 implies that this radiative forcing, if maintained, will eventually yield about 1.2°C of warming. Over the instrumental record, the global mean temperature has risen by about 0.7°C, implying another 0.5°C remaining after the ocean sufficiently heatsup. How much has the heat content of the ocean already increased? Based on available hydrographic data from 1955-1998, the world ocean between the surface and 3000m depth gained $\sim 1.6 \times 10^{22}$J. Compared with atmospheric kinetic energy this is a very large number.

An obvious shortcoming of the concept of equilibrium climate sensitivity is that radiative forcing is always changing. Consider explosive volcanic eruptions. While the global radiative forcing from a single eruption can be very significant (2-3W m^{-2} at peak), the forcing is short-lived (several years) such that the system can never come into equilibrium with it (while the global surface temperature can be temporarily reduced by several tenths of a degree, this is much smaller than the calculated temperature change in equilibrium with the peak forcing). Similarly, the system could never be in equilibrium with solar variability associated with the

11-year sunspot cycle. If we were to somehow freeze the current radiative forcing from human activities at its present value, the climate system would eventually approach a new temperature in equilibrium with it (assuming no complications like multiple volcanic eruptions). However, radiative forcing from human activities has grown over the past century and will continue to grow in the future, meaning that the equilibrium temperature value has changed and will continue to change. Put differently, the picture over the past 100 years and into the future is a climate system constantly trying to catch up with a growing radiative forcing but always lagging behind it.

4. The importance of framework

While the distinction between climate forcing and feedback is fairly straightforward when considering changes in globally averaged temperature, it must be stressed that this distinction may change if adopting a different framework, such as the evaluation of regional climate variability and change. For example, due to loss of its sea ice cover, rises in surface air temperature are expected to be especially pronounced over the Arctic Ocean. In the framework of human-induced global climate change, this may be viewed as part of the feedback process that amplifies the global average temperature response to increased greenhouse gas concentrations. However, if one were to conduct a regional study of the Arctic, one could legitimately view the sea ice loss as a forcing on Arctic temperature change. Similarly, global climate change may be attended by shifts in patterns of atmospheric circulation, precipitation and cloud cover. While on the global scale these would be viewed as feedbacks, investigations of regional impacts could view them as forcings.

Another framework issue regards how one views transitions between glacial and interglacial conditions. While changes in ice sheet area and greenhouse gas concentrations during these transitions are appropriately viewed as slow feedbacks, if one considers full glacial and interglacial conditions as two equilibrium states, these slow feedbacks may instead be thought of as climate forcings. With estimates of the global temperature change between the equilibrium states and the forcings, one then has another way to estimate equilibrium climate sensitivity. Numbers obtained from this approach turn out to agree fairly well with those coming from global climate models. Hence, in summary, depending on the chosen framework, one person's feedback may be another person's forcing.

5.3.3 The Climatic Record

1. The geological Record

Understanding the significance of climatic trends over the past 100 years requires that they be viewed against the backdrop of earlier conditions. On geological timescales, global climate has undergone major shifts between generally warm, ice-free states and Ice Ages with continental ice sheets. There have been at least seven major Ice Ages through geological time. The first occurred 2500 million years ago (Ma) in the Archean period, followed by three more between 900 and 600 Ma, in the Proterozoic. There were two Ice Ages in the Paleozoic era (the Ordovician, 500-430 Ma; and the Permo-Carboniferous, 345-225 Ma). The most recent Ice Age began about 34 Ma in Antarctica at the Eocene/Oligocene boundary and about three million years ago in northern high latitudes. At present, we are considered to be still within this most recent Ice Age, albeit in the warm part of it known as the Holocene, which began about 11.5 ka. While the total volume of land ice today (mostly comprising the Antarctic and Greenland ice sheets) is certainly much smaller than it was at 20 ka, it is still substantial compared to other times of the earth's past.

Major Ice Ages and ice-free periods can be linked to a combination of external and internal climate forcing (plate tectonics, greenhouse gas concentrations, solar irradiance). The ice sheets of the Ordovician and Permo-Carboniferous periods formed in high southern latitudes on the former mega-continent of Gondwanaland. Uplift of the western cordilleras of North America and the Tibetan Plateau by plate movements during the Tertiary period (50-2 Ma) caused regional aridity to develop in the respective continental interiors. However, geographical factors are only part of the explanation of climate variations. For example, warm high-latitude conditions during the mid-Cretaceous period, about 100 Ma, may be attributable to atmospheric concentrations of carbon dioxide three to seven times higher than at present, augmented by the effects of alterations in land-sea distribution and ocean heat transport.

Much more is known about ice conditions and climate forcings through the Quaternary, which began about 2.6 million years ago, comprising the Pleistocene (2.6 Ma-11.5 ka) and the Holocene (11.5 ka-present) epochs. It is abundantly clear that this most recent Ice Age we live in was far from being uniformly cold. Instead it was characterized by oscillations between glacial and interglacial conditions. Eight cycles of global ice volume are recorded in land and ocean sediments during the last 0.8-0.9 Ma, each averaging roughly 100ka, with only 10 percent of each cycle as warm as the twentieth century. Each glacial period was in turn characterized by abrupt terminations. Because of reworking of sediments, only four or five of these glaciations are identified from terrestrial records. Nevertheless, it is likely that all were characterized by large ice sheets covering northern North America and northern Europe. Sea-levels were also lowered by about 130 m due to the large volume of water locked up in the ice. Records from tropical lake basins show that these regions were generally arid at those times. Prior to 0.9 Ma the timing of glaciations is more complex. Ice volume records show a dominant 41 ka periodicity, while ocean records of calcium carbonate indicate fluctuations of 400 ka.

These periodicities are linked to the Milankovich forcings discussed earlier. The precession signature (19 and 23 ka) is most apparent in low-latitude records, whereas that of obliquity (41 ka) is represented in high latitudes. However, the 100 ka orbital eccentricity signal is generally dominant overall. The basic idea is that onset of glacial conditions is initiated by Milankovich forcings that yield summer cooling over the northern land masses. This favors survival of snow cover through summer, feedback promoting further cooling and ice sheet growth, leading to even further cooling through slow feedbacks in the carbon cycle discussed earlier. Onset of an interglacial works the other way, with Milankovich forcings promoting initial warming over the northern land masses, setting feedbacks into motion to give further warming and ice melt.

2. The last glacial cycle and postglacial conditions

The last interglacial, known as the Eemian, peaked about 125 ka. The last glacial cycle following the Eemian was itself characterized by periods of extensive ice (known as stades) and less extensive ice (known as interstades), Maximum global ice volume (the Last Glacial Maximum, or LGM) occurred around 25-18 ka. The LGM ended with abrupt warming between about 15 and 13 ka, depending on latitude and area, interrupted by a cold regression called the Younger Dryas (13-11.7 ka). This was then followed by a renewed sharp warming trend. The Holocene (our present interglacial) is considered to begin at 11.5 ka, after the close of the Younger Dryas event. Based on assessments of Milankovich forcings, the present interglacial should last for at least another 30,000 years. A particularly striking feature of the last glacial cycle is rapid millennialscale changes between warm and cold conditions, known as Dansgaard-Oeschger (D-O) cycles. The Younger Dryas event is considered to be the last of these D-O cycles. As is evident in a number of proxy records, the onset and termination of the Younger Dryas cold event, with a switch from near glacial to interglacial climate conditions and back again, apparently occurred within a five-year time interval for both transitions! The processes driving D-O events like the Younger Dryas are still incompletely understood, but likely in some way involve massive discharges of fresh water from melting ice sheets to the North Atlantic that disrupted the Atlantic thermohaline circulation.

Early Holocene warmth around 10 ka is attributed to July solar radiation being 30-40W m^{-2} greater than now in northern mid-latitudes, again due to Milankovich effects. Following the final retreat of the continental ice sheets from Europe and North America between 10,000 and 7000 years ago, the climate rapidly ameliorated in middle and higher latitudes. In the subtropics this interval was also generally wetter, with high lake levels in Africa and the Middle East. A Holocene Thermal Maximum (HTM) was reached in the mid-latitudes about 5000 years ago, when summer temperatures were 1–2° C higher than today and the Arctic tree line was several hundred kilometers further north in Eurasia and North America. By this time, subtropical desert regions were again very dry and were largely abandoned by primitive peoples.

A temperature decline set in around 2000 years ago with colder, wetter conditions in Europe and North America. Although temperatures have not since equaled those of the HTM (we are getting close), a relatively warmer interval (or intervals) occurred between the ninth and mid-fifteenth centuries AD. Summer temperatures in Scandinavia, China, the Sierra Nevada (California), Canadian Rocky Mountains and Tasmania exceeded those that prevailed until the late twentieth century.

3. The past 1000 years

Temperature reconstructions for the Northern Hemisphere over the past millennium are based on several types of proxy data, but especially dendrochronology, ice cores and historical records. A reconstruction based on such proxies for the past millennium. Until about AD 1600 there is still considerable disparity in different estimates of decadal mean values and their range of variation. Conditions appear to have been slightly warmer between AD 1050 and 1330 than between 1400 and 1900. There is evidence in Western and Central Europe for a warm phase around AD 1300. Icelandic records indicate mild conditions up until the late twelfth century, and this phase was marked by the Viking colonization of Greenland and the occupation of Ellesmere Island in the Canadian Arctic by the Inuit.

Deteriorating conditions followed. This cool period, known as the 'Little Ice Age', was associated with extensive Arctic sea ice and glacier advances in some areas to maximum positions since the end of the last glacial cycle. These advances occurred at dates ranging from the mid-seventeenth to the late nineteenth century in Europe, as a result of the lag in glacier response and regional variability. The coldest interval of the Little Ice Age in the Northern Hemisphere was AD 1570-1730. What caused the Little Ice Age is not entirely clear. Reduced solar output associated with the Maunder Minimum in sunspot activity (1645-1715) likely played a role, as did increased volcanic activity.

Long instrumental records for stations in Europe and the eastern United States indicate that the warming trend that ended the Little Ice Age began at least by the mid-nineteenth century. The time series of global annual averaged surface air temperature from instrumental records shows a significant temperature rise of about 0.7° C from 1880 through 2007. Both hemispheres have participated in this warming, but it is most pronounced in the Northern Hemisphere. Warming in turn encompasses both land and ocean regions, being stronger over land . Warming has been smallest in the tropics and largest in northern high latitudes. Warming is in turn strongest during winter. The general temperature rise has not been continuous, however, and four basic phases may be identified in the global record :

1. 1880-1920, during which there was an oscillation within extreme limits of about 0.3° C but no trend.
2. 1920-mid-1940s, during which there was considerable warming of approximately 0.4° C; this warming was most strongly expressed in northern high latitudes.
3. Mid-1940s-early 1970s, during which there were oscillations within extreme limits of about 0.4° C, with the Northern Hemisphere cooling slightly on average and the Southern Hemisphere remaining fairly constant in temperature. Regionally, northern Siberia, the eastern Canadian Arctic and

Alaska experienced a mean lowering of winter temperatures by 2-3° C between 1940 and 1949 and 1950 and 1959; this was partly compensated by a slight warming in the western United States, Eastern Europe and Japan.

4. Mid-1970s-2008, during which there was a marked overall warming of about 0.5° C, but with strong regional variability.

Based on balloon soundings and assessments from satellite sounders, lower tropospheric temperatures over the period 1958 to the present have increased at slightly higher rates than at the surface. This interpretation, however, must acknowledge discontinuities and biases in the time series introduced by changing satellites, orbit decay, drift and other factors. There is evidence that balloon soundings may have a cooling bias.

Global mean surface temperatures during the past decade reached their highest levels on record and probably for the last millennium. In the NASA GISS analysis, the warmest year on record was 2005, with 2007 and 1998 tied for second warmest. Rankings based on other global temperature analyses (*e.g.*, from the Climatic Research Unit of the UK) differ somewhat, but tell the same basic story of very warm conditions for the past decade. The key spatial feature of change over the past decade is very strong warming over northern high latitudes. This is especially apparent in autumn and winter and over the Arctic Ocean. It is linked to both changes in atmospheric circulation and declining sea ice extent. Regarding the latter, anomalous areas of open water in autumn and winter allow for large heat fluxes from the ocean surface to the lower atmosphere. Note also the strong warming over the Antarctic Peninsula.

One of the manifestations of recent warming is a longer growing season. For example, in central England, the growing season (defined as daily mean temperature > 5° C for five days in succession) lengthened by 28 days over the twentieth century and was about 270 days in the 1990s compared with around 230-250 days in the eighteenth to nineteenth centuries. In the Arctic, there is strong evidence of links between recent warming and regional transitions from tundra to shrub vegetation. A further tendency of the past 50 years or so is a decrease in the diurnal temperature range; night-time minimum temperatures increased by 0.8° C during 1951-1990 over at least half of the northern land areas compared with only 0.3° C for daytime maximum temperatures. This appears to be mainly a result of increased cloudiness, which, in turn, may be a response to increased greenhouse gases and tropospheric aerosols. However, the linkages are not yet adequately determined.

Precipitation changes are much more difficult to characterize. The period since 1900 has seen an overall increase in precipitation north of about 30° N. By contrast, since the 1970s, there have been decreases over much of the tropics and subtropics. However, these general features mask strong seasonal, regional and temporal variations. As an example of this complexity, the variations in tropical and subtropical precipitation overland areas through the mid-1990s. Since the mid-twentieth century, decreases in precipitation dominate much of the region from North Africa eastward to Southeast Asia and Indonesia. Many of the dry episodes are associated with El Niño events. Equatorial South America and Australasia also show ENSO influences. The Indian monsoon area shows wetter and drier intervals; the drier periods are evident in the early twentieth century and during 1961-1990.

As a further example of complexity, West African records for the twentieth century show a tendency for both wet and dry years to occur in runs of up to 10 to 18 years. Precipitation minima were experienced in the 1910s, 1940s and post-1968, with intervening wet years, in all of sub-Saharan West Africa. Throughout the two northern zones outlined, means for 1970-1984 were generally less than 50 percent of those for 1950-1959, with deficits during 1981-1984 equal to or exceeding those of the disastrous early 1970s' drought. The deficits continued into the 1990s. It has been suggested that the severe drought is related to weakening of the tropical easterly jet stream and limited northward penetration of the West African southwesterly monsoon flow. However, Sharon Nicholson attributes the precipitation fluctuations to contraction and expansion of the Saharan arid core rather than to north-south shifts of the desert margin. In Australia, rainfall changes have been related to changes in the location and intensity of subtropical anticyclones and associated changes in atmospheric circulation. Winter rainfall decreased in southwestern Australia while summer rainfall increased in the southeast, particularly after 1950. Northeastern Australia shows decadal oscillations and large inter-annual variability.

Winter and summer fluctuations in precipitation for England and Wales. There is wide interannual variability and some large decadal shifts are evident. There are also longer-term changes. For example, winters have been wetter from about

1860 onward compared with the earlier part of the record. Changes also depend on season - while winter rainfall increased from 1960 to the end of the record, summer precipitation generally decreased over the same time. Records for individual stations show that even over relatively short distances there may be considerable differences in the magnitude of anomalies, especially in an east-west direction across the British Isles.

The late twentieth and early twenty-first century has seen more frequent climatic extremes. For example, Britain has experienced several major droughts during this period (1976, 1984, 1989-1992 and 1995); seven severe winter cold spells occurred between 1978 and 1987 (compared with only three in the preceding 40 years); and several major windstorms (1987, 1989 and 1990) were recorded. The driest 28-month spell (1988–1992) recorded in Britain since 1850 was followed by the wettest 32-month interval of the twentieth century. Europe experienced unprecedented heatwaves in 2003 and 2008. In the United States, recent decades saw a marked increase in the inter-annual variability of mean winter temperatures and total precipitation. The year 1983 saw the most intense El Niño event for a century, followed by a comparable event in 1998. There is also some evidence of an increase in the frequency of intense hurricanes (Category 4 and 5).

5.4 National Action Plan on Climate Change (NAPCC)

The National Action Plan on Climate Change (NAPCC) was released by the Prime Minister on 30th June, 2008. It outlines a national strategy that aims to enable the country to adapt to climate change and enhance the ecological sustainability of India's development path. It stresses that maintaining a high growth rate is essential for increasing living standards of the vast majority of people of India and reducing their vulnerability to the impacts of climate change.

5.4.1 Principles of NAPCC

- Protecting the poor through an inclusive and sustainable development strategy, sensitive to climate change
- Achieving national growth and poverty alleviation objectives while ensuring ecological sustainability
- Efficient and cost-effective strategies for end-use demand-side management

- Extensive and accelerated deployment of appropriate technologies for adaptation and mitigation
- New and innovative market, regulatory, and voluntary mechanisms for sustainable development
- Effective implementation through unique linkages – with civil society, LGUs, and public-private partnerships

There are eight National Missions which form the core of the National Action Plan. They focus on promoting understanding of climate change, adaptation and mitigation, energy efficiency and natural resource conservation.

The eight National Missions on climate change are :

1. National Solar Mission
2. National Mission for Enhanced Energy Efficiency
3. National Mission on Sustainable Habitat
4. National Water Mission
5. National Mission for Sustaining the Himalayan Eco-system
6. National Mission for a Green India
7. National Mission for Sustainable Agriculture
8. National Mission on Strategic Knowledge for Climate Change

1. National Solar Mission (NSM)

The NSM was launched in January 2010, with the objective of establishing India as a global leader in solar energy, by creating the policy conditions for solar technology diffusion across the country as quickly as possible.

The initial target of NSM was to install 20 GW solar power by 2022. This was upscaled to 100 GW in early 2015. Numerous facilitative programmes and schemes under the Mission have driven the grid connected solar power installed capacity from 25 MW in the year 2010-11 to about 36.32 GW as on 31st October 2020. An additional 58.31 GW solar power capacity is currently under installation/ tendering process.

Objectives

The objective of the National Solar Mission is to establish India as a global leader in solar energy, by creating the policy conditions for its diffusion across the country as quickly as possible. The Mission adopts a three-phase approach, Phase 1 (up to 2012 - 13), Phase 2 (2013 - 17) and Phase 3 (2017 - 22). The immediate aim of the Mission is to focus on setting up an enabling environment for solar technology penetration in the country both at a centralized and decentralized level.

2. **National Mission for Enhanced Energy Efficiency (NMEEE)**

   NMEEE aims to strengthen the market for energy efficiency by creating conducive regulatory and policy regime and has envisaged fostering innovative and sustainable business models to the energy efficiency sector. The Mission is implemented since 2011.

   NMEEE consists of four initiatives to enhance energy efficiency in energy intensive industries :

   - Perform, Achieve and Trade (PAT)
   - Market Transformation for Energy Efficiency (MTEE)
   - Energy Efficiency Financing Platform (EEFP)
   - Framework for Energy Efficient Economic Development (FEEED)

3. **National Mission on Sustainable Habitat**

   The National Mission on Sustainable Habitat was approved by the Prime Minister‘s Council for Climate Change in June 2010.

   The key deliverables of the Mission include :

   - Development of sustainable habitat standards that lead to robust development strategies while simultaneously addressing climate change related concerns
   - Preparation of city development plans that comprehensively address adaptation and mitigation concerns
   - Preparation of comprehensive mobility plans that enable cities to undertake long-term, energy efficient and cost-effective transport planning

- Capacity building for undertaking activities relevant to the Mission

4. National Water Mission

A National Water Mission will ensure integrated water resource management helping to conserve water, minimize wastage and ensure more equitable distribution both across and within states. The Mission will take into account the provisions of the National Water Policy and develop a framework to optimize water use by increasing water use efficiency by 20 percent through regulatory mechanisms with differential entitlements and pricing. It will seek to ensure that a considerable share of the water needs of urban areas are met through recycling of waste water, and ensuring that the water requirements of coastal cities with inadequate alternative sources of water are met through adoption of new and appropriate technologies such as low temperature desalination technologies that allow for the use of ocean water.

NWM has identified five goals which are mentioned below :

- Comprehensive water data base in public domain and assessment of the impact of climate change on water resource
- Promotion of citizen and state actions for water conservation, augmentation and preservation
- Focused attention to vulnerable areas including over-exploited areas
- Increasing water use efficiency by 20 percent
- Promotion of basin level integrated water resources management

5. National Mission for sustaining the Himalayan Eco-system

This particular mission sets the goal to prevent melting of the Himalayan glaciers and to protect biodiversity in the Himalayan region.

The Himalayan ecosystem as a national mission will focus on the rapid generation of four types of national capacities, which deal with :

- Human and knowledge capacities
- Institutional capacities
- Capacities for evidence-based policy building and governance
- Continuous self-learning for balancing between forces of Nature and actions of mankind

The mission attempts to address some important issues concerning

- Himalayan Glaciers and the associated hydrological consequences
- Biodiversity conservation and protection
- Wildlife conservation and protection
- Traditional knowledge societies and their livelihood and
- Planning for sustaining the Himalayan Ecosystem

6. National Mission for a Green India

The Cabinet Committee on Economic Affairs approved a proposal of the Ministry of Environment and Forests for a National Mission for a Green India (GIM) as a Centrally Sponsored Scheme.

GIM puts "greening" in the context of climate change adaptation and mitigation. Greening is meant to enhance ecosystem services such as carbon sequestration and storage (in forests and other ecosystems), hydrological services and biodiversity; as well as other provisioning services such as fuel, fodder, small timber and non- timber forest products (NTFPs).

The Mission aims at responding to climate change by a combination of adaptation and mitigation measures, which would help :

- Enhancing carbon sinks in sustainably managed forests and other ecosystems
- Adaptation of vulnerable species/ecosystems to the changing climate
- Adaptation of forest-dependent communities

The objectives of the Mission are :

- Increased forest/tree cover on 5 mha of forest/non-forest lands and improved quality of forest cover on another 5 mha (a total of 10 mha)
- Improved ecosystem services including biodiversity, hydrological services and carbon sequestration as a result of treatment of 10 mha
- Increased forest-based livelihood income of about 3 million households living in and around the forests

- Enhanced annual CO_2 sequestration by 50 to 60 million tonnes in the year 2020

7. **National Mission for Sustainable Agriculture**

   National Mission for Sustainable Agriculture (NMSA) has been made operational from the year 2014-15, it aims at making agriculture more productive, sustainable, remunerative and climate resilient by promoting location specific integrated /composite farming systems; soil and moisture conservation measures; comprehensive soil health management; efficient water management practices and mainstreaming rain-fed technologies.

8. **National Mission on Strategic Knowledge for Climate Change**

   The National Mission on Strategic Knowledge for Climate Change (NMSKCC) seeks to build a vibrant and dynamic knowledge system that would inform and support national action for responding effectively to the objective of ecologically sustainable development.

5.5 Green Building

While there are several different definitions of Green Building out there, it is commonly accepted as the planning, design, construction, and processes of buildings with several central, foremost reflections: energy use, water use, indoor environmental quality, material section and the building's effects on its site.

A parallel concept is natural building, which is usually on a smaller scale and tends to focus on the use of natural materials that are available locally. It is a holistic concept that begins with the understanding that the built environment can have both a positive and negative impact on the natural environment as well as the people living in the buildings every day. Green building is an attempt to reduce the positive and negative of these effects throughout the life cycle of a building.

Other related topics include sustainable design and green architecture. Sustainability can be defined as meeting the needs of current generations, without compromising the ability to meet the needs of future generations.

The U.S. EPA says "Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation, and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or high-performance building."

5.5.1 Green building concept

The 'Green Building' concept is gaining importance in various countries, including India. These are buildings that ensure that waste is minimized at every stage during the construction and operation of the building, resulting in low costs, according to experts in the techniques associated with the 'Green Building' include measures to prevent erosion of soil, rainwater harvesting, use of solar energy, preparation of landscapes to reduce heat, reduction in usage of water, recycling of waste-water and use of world-class energy-efficient practices.

Green building is a whole-system approach to the design and construction of buildings that conserve and build energy, water, and material resources and are more healthy, safe and comfortable. Many think of solar panels when they think of "green" buildings.

Green building responds to the realization that the way we are building everything from houses to skyscrapers is not sustainable. Many health problems today arise from poor indoor air quality and exposure to toxins contained in commonly used construction products. Green building practices can eliminate these health-damaging conditions.

5.5.2 Green buildings in India

A green building is one which uses less water, optimizes energy efficiency, conserves natural resources, generates less waste and provides healthier spaces for occupants, as compared to a conventional building. IGBC is a leading green building movement in the country.

The Indian Bureau of Energy Efficiency (BEE) launched the Energy Conservation Building Code (ECBC). The code is set for energy efficiency standards for design and construction with any building of minimum conditioned area of 1,000 m^2 and a connected demand of power of 500 KW or 600 KVA. The energy performance index of the code is set from 90 kW·h/sqm/year to 200 kW·h/sqm/year where any buildings that fall under the index can be termed as "ECBC Compliant Building"

5.5.3 Green building materials

Renewable sources : Forests

Reuse from waste : old plumbing, doors, *etc*.

Solar Tiles : Exist to simply protect a building. They spend a large portion of the day absorbing energy from the sun.

Paper Insulation : Made from recycled newspapers and cardboard then filled with chemical foam. Insect-resistant & fire retardant

Wool brick : Obtained by adding wool and a natural polymer found in seaweed to the clay of the brick, 37% more strength than burnt bricks. Resistant for cold and wet climate

Sustainable Concrete : Crushed glass, Wood chips or slag – a byproduct of steel manufacturing. Reduces the emission of CO_2

5.5.4 Benefits of Green building

- Energy Efficiency
- Water Efficiency
- Efficient Technologies
- Easier Maintenance
- Return on Investment
- Improved Indoor Air Quality
- Waste Reduction
- Temperature Moderation
- Water Conservation
- Economical Construction For Poor
- Healthier Lifestyles and Recreation
- Improved Health.

5.5.5 Examples of green buildings in India

- ITC Green Centre, Gurgaon

- Patni (i-GATE) Knowledge Center, Noida
- Olympia Tech Park, Chennai
- Indira Paryavaran Bhawan

5.6 GRIHA Rating Norms

The GRIHA full form is **Green Rating for Integrated Habitat Assessment.** This tool of rating the habitats helps people to assess the overall performance of their dwelling places, precisely buildings. This takes into consideration the various benchmarks that are nationally accepted.

A building has a life cycle. The rating system observes how a building performs throughout its life cycle. Special emphasis is put on holistic environmental performance and its evaluation. Thus, a set of standards are established. Those buildings that abide by these standards get marked as 'green buildings.

GRIHA is actually a Sanskrit word that means 'abode'. This takes into consideration the interaction of human habitats with the surrounding environment. Now, this interaction can happen in more than one way. Construction of the building marks the start of the life cycle. While the building is demolished completely, it is marked as the end of the life cycle. However, buildings consume huge amounts of resources throughout their life cycle. These resources are materials, energy, and water, among others.

Wastes are produced by these buildings directly as municipal wastes and indirectly as the emissions from the process of electricity generation. GRIHA is a system that aims to minimize the resource consumption and waste generation of the buildings. This way, the ecological impact of the same is also reduced.

Thus, the GRIHA system quantifies the related aspects of resource consumption, renewable energy adoption, and waste generation.

International Recognition of the GRIHA

In the international context, the GRIHA rating system serves as an innovative tool in the hands of the United Nations for the purpose of sustainable development. This acts as a significant tool for the implementation of renewable energy in the construction sector with the help of 'The Climate Reality Project'.

The "Common Carbon Metric" is considered to be a major tool in this context that helps in data collection on international building energy. For the purpose of data collection, inputs are taken from the GRIHA.

Figure 5.1 : GRIHA

Indian Implementation of the GRIHA

The Indian government accepts the GRIHA standards as a much-needed standard for the ecological balance in the country. Let's take the example of the Maharashtra government. This government provides incentives to the occupants and developers of projects that comply with the GRIHA standards.

GRIHA has been adopted by the Government of Delhi Cabinet as well as by the cabinets of other major states.

5.6.1 The benefits of GRIHA

On a broader scale, this system, along with the activities and processes that lead up to it, will benefit the community at large with the improvement in the environment by reducing GHG (greenhouse gas) emissions, reducing energy consumption and the stress on natural resources.

Some of the benefits of a green design to a building owner, user, and the society as a whole are as follows:

- Reduced energy consumption without sacrificing the comfort levels
- Reduced destruction of natural areas, habitats, and biodiversity, and reduced soil loss from erosion *etc.*
- Reduced air and water pollution (with direct health benefits)
- Reduced water consumption
- Limited waste generation due to recycling and reuse
- Reduced pollution loads
- Increased user productivity
- Enhanced image and marketability

Table 5.1 : GRIHA rating system

GRIHA v. 2019			
Section	**Criterion No.**	**Criterion Name**	**Maximum Points**
1. Sustainable Site Planning	1	Green Infrastructure	5
	2	Low Impact Design	5
	3	Design to Mitigate UHIE	2
2. Construction Management	4	Air and Soil Pollution Control	1
	5	Top Soil Preservation	1
	6	Construction Management Practices	2
3. Energy Efficiency	7	Energy Optimization	12
	8	Renewable Energy Utilization	5
	9	Low ODP and GWP Materials	1
4. Occupant Comfort	10	Visual Comfort	4
	11	Thermal and Acoustic Comfort	2
	12	Maintaining Good IAQ	6
5. Water Management	13	Water Demand Reduction	3
	14	Wastewater Treatment	3
	15	Rainwater Management	5

Section	Criterion No.	Criterion Name	Maximum Points
6. Solid Waste Management	16	Water Quality and Self-Sufficiency	5
	17	Waste Management-Post Occupancy	4
	18	Organic Waste Treatment On-Site	2
7. Sustainable Building Materials	19	Utilization of Alternative Materials in Building	5
	20	Reduction in GWP through Life Cycle Assessment	5
	21	Alternative Materials for External Site Development	2
8. Life Cycle Costing	22	Life Cycle Cost Analysis	5
9. Socio-Economic Strategies	23	Safety and Sanitation for Construction Workers	1
	24	Universal Accessibility	2
	25	Dedicated Facilities for Service Staff	2
	26	Positive Social Impact	3
10. Performance Metering and Monitoring	27	Commissioning for Final Rating	7
	28	Smart Metering and Monitoring	0
	29	Operation and Maintenance Protocol	0
Total Points			100
11. Innovation	30	Innovation	5
Grand Total Points			100 + 5

Rating Threshold

GRIHA V 2019 Rating Thresholds	GRIHA Rating
25-40	★
41-55	★ ★
56-70	★ ★ ★
71-85	★ ★ ★ ★
86 or more	★ ★ ★ ★ ★

5.7 COPs

A conference of the parties (COP; French : Conférence des Parties, CP) is the supreme governing body of an international convention (treaty, written agreement between actors in international law). It is composed of representatives of the member states of the convention and accredited observers. Scope of the COP is to review the "implementation of the Convention and any other legal instruments that the COP adopts and take decisions necessary to promote the effective implementation of the Convention".

Conventions with a COP include :

- Basel Convention
- Chemical Weapons Convention
- Convention on Biological Diversity
- 2012 Hyderabad Biodiversity Conference (COP11)
- 2022 United Nations Biodiversity Conference (COP15)
- Convention on the Conservation of Migratory Species of Wild Animals
- Convention on International Trade in Endangered Species of Wild Fauna and Flora
- Kyoto Protocol
- Minamata Convention on Mercury
- Ramsar Convention
- Rotterdam Convention
- Stockholm Convention on Persistent Organic Pollutants
- Treaty on the Non-Proliferation of Nuclear Weapons
- United Nations Convention to Combat Desertification
- United Nations Convention against Corruption
- United Nations Framework Convention on Climate Change

- United Nations Climate Change conference
- WHO Framework Convention on Tobacco Control

Location	Session	Conference
Sharm el-Sheikh, Egypt	COP 27	Sharm el-Sheikh Climate Change Conference - November 2022
Glasgow, United Kingdom of Great Britain and Northern Ireland	COP 26	Glasgow Climate Change Conference – October-November 2021
Madrid, Spain	COP 25	UN Climate Change Conference - December 2019
Katowice, Poland	COP 24	Katowice Climate Change Conference – December 2018
Bonn, Germany	COP 23	UN Climate Change Conference - November 2017
Marrakech, Morocco	COP 22	Marrakech Climate Change Conference - November 2016
Paris, France	COP 21	Paris Climate Change Conference - November 2015
Lima, Peru	COP 20	Lima Climate Change Conference - December 2014
Warsaw, Poland	COP 19	Warsaw Climate Change Conference - November 2013
Doha, Qatar	COP 18	Doha Climate Change Conference - November 2012
Durban, South Africa	COP 17	Durban Climate Change Conference - November 2011
Cancun, Mexico	COP 16	Cancún Climate Change Conference - November 2010
Copenhagen, Denmark	COP 15	Copenhagen Climate Change Conference - December 2009
Poznan, Poland	COP 14	Poznan Climate Change Conference - December 2008

Location	Session	Conference
Bali, Indonesia	COP 13	Bali Climate Change Conference - December 2007
Nairobi, Kenya	COP 12	Nairobi Climate Change Conference - November 2006
Montreal, Canada	COP 11	Montreal Climate Change Conference - December 2005
Buenos Aires, Argentina	COP 10	Buenos Aires Climate Change Conference - December 2004
Milan, Italy	COP 9	Milan Climate Change Conference - December 2003
New Delhi, India	COP 8	New Delhi Climate Change Conference - October 2002
Marrakech, Morocco	COP 7	Marrakech Climate Change Conference - October 2001
Bonn, Germany	COP 6-2	Bonn Climate Change Conference - July 2001
The Hague, Netherlands	COP 6	The Hague Climate Change Conference - November 2000
Bonn, Germany	COP 5	Bonn Climate Change Conference - October 1999
Buenos Aires, Argentina	COP 4	Buenos Aires Climate Change Conference - November 1998
Kyoto, Japan	COP 3	Kyoto Climate Change Conference - December 1997

5.8 Summary

The most fundamental measure of the earth's climate state is the global averaged surface air temperature. It is influenced by a variety of climate forcing factors operating on a suite of timescales. Climate variations over timescales of millions of years can be linked to plate tectonics. The great Ice Ages and interglacial that have characterized the past two million years can be linked to periodicities in the earth's orbit around the sun, influencing the seasonal distribution of solar radiation over different parts of the surface. The observed increase in global mean surface air temperature over the past 100 years may be attributed primarily to human-induced increases in atmospheric carbon dioxide and other greenhouse gases, partly compensated by the cooling effects of aerosol loading. These are known as radiative forcings in that they alter the globally averaged radiation budget at the top of the atmosphere. Solar variability, another radiative forcing, has played a minor role since the mid-twentieth century. The general rise in global mean surface temperature over the past 100 years contains inter-annual to multi-decadal variations. These reflect natural internal variability in the coupled atmosphere-ocean-land system as well as transient radiative forcings such as large volcanic eruptions (*e.g.*, Mt. Pinatubo).

The magnitude of the response of global temperature to a radiative forcing of given magnitude or set of forcings in combination, depends on the climate feedbacks. Positive feedbacks dominate and hence act to amplify the temperature response to a forcing. In terms of human-induced climate change, the most important are the fast water vapor and ice-albedo feedbacks. Climate projections through the twenty-first century, assuming a variety of emission scenarios for greenhouse gases and aerosols, indicate a mean global temperature increase in the range of 2-4° C by the year 2100, together with sea-level rises of 200-500mm. Given the rapid growth of greenhouse gas concentrations in recent decades, the effects of ice sheet dynamics and other wild cards in the system, these may be underestimates. The Arctic will eventually become free of sea ice in summer. Warming will also be accompanied by continued shrinking of glaciers, ice caps and permafrost, changes in the hydrologic cycle, atmospheric circulation, and vegetation.

5.9 Questions/Self-Assessment questions

1. Briefly describe different record of climate change.
2. What is national action plan on climate change (NAPCC)?
3. What are the principals of NAPCC?
4. What do you know about the green building?
5. What are the benefits of green building?

6. What are the benefits of GRIHA rating?
7. Define COPs? Mentioned some important COP.

5.10 Suggested Readings

1. https://www.grihaindia.org/griha-rating
2. https://www.themightyearth.com/concept-of-green-building-and-benefits/
3. https://dst.gov.in/sites/default/files/NMSKCC_mission%20document%201.pdf
4. https://dst.gov.in/climate-change-programme
5. http://moef.gov.in/wp-content/uploads/2018/07/CC_ghosh.pdf
6. https://vikaspedia.in/energy/policy-support/environment-1/climate-change
7. https://static.pib.gov.in/WriteReadData/specificdocs/documents/2021/dec/doc202112101.pdf