PHYSICAL GEOGRAPHY

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Physical Geography

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Introduction to Physical Geography

A geographer explains the phenomena in a frame of cause and effect relationship, as it does not only help in interpretation but also foresees the phenomena in future.

The word geography comes from two Greek roots. ‘Geo’ refers to the earth, and ‘graphy’ means picture or writing. Geography examines, describes, and explains the earth – its variation from time to time and from place to place. Geography is often called the "spatial science" because it includes the recognition, analysis, and explanation of likenesses and differences, or of variations in phenomena as they are distributed on the earth's surface (through earth space).

Geography is both a physical and a social science. In its concern with the natural environment, geography is very much a physical science. Yet geography also examines humanity’s two-way relationship with the earth and is thus a social science as well Cultural or human geography is the study of human activity and of the results of that activity. The human geographer studies such subjects as population distribution, cities and urbanization, natural resource utilization, industrial location, and transportation networks. When a geographic study concentrates primarily on the
physical and human features of a specific region, such as India, we call this regional geography. In other word Geography is a fundamental science that helps us to understand our physical environment with its elements and components forming a complex structure of the earth which is the only habitable planet in the solar system. Geographers study the factors responsible for spatial distribution and variation of people, places with their locations. Physical geographers explain the phenomenon of evolution of landforms, tectonic movements, weather and climate, ocean characteristics and properties, flora and fauna.

In this global age, the study of geography is absolutely essential to an educated citizenry of a nation whose influence extends throughout the world. Geography deals with location; and a good sense of where things are, especially in relation to other things in the world, is an invaluable asset whether you are traveling, conducting international business, or sitting at home reading the newspaper. Thus, geography was perceived to study all those phenomena which vary over space. Geographers do not study only the variations in the phenomena over the earth’s surface (space) but also study the associations with the other factors which cause these variations. For example, cropping patterns differ from region to region but this variation in cropping pattern, as a phenomenon, is related to variations in soils, climates, demands in the market, capacity of the farmer to invest and technological inputs available to her/him. Thus, the concern of geography is to find out the causal relationship between any two phenomena or between more than one phenomenon. The geographical phenomena, both the physical and human, are not static but highly dynamic. They change over time as a result of the interactive processes between ever changing earth and untiring and ever-active human beings.

Physical geography encompasses the study of the natural aspects of the human environment. That is, physical geographers look at the atmospheric elements that affect the surface of the earth and that together make up weather and climate. They examine the variations in soil and in natural vegetation. The varieties of water bodies on earth and their movements, effects, and other characteristics are subjects of physical geography, as are the landforms of the earth, their formation, and their modification. Yet although physical geographers emphasize the elements that make up our physical environment, they do not ignore the effect of people on those elements.

### 1.1 Definition of Physical Geography

Physical geography is that branch of systematic geography (physical and human) that examines activities. Physical geography differs from other sciences in that it focuses on the world around us from changes in daily weather conditions to landforms we travel every day. Physical geography is not only the agglomeration of different branches of earth and natural sciences like geomorphology, climatology, meteorology, pedology, geology etc. but it also studies the patterns of interactions between human activities and physical environment. Physical geography can be defined differently as follows:
1. Physical geography is the study of forces that influence the surface of earth.
2. Physical geography is to study natural phenomena.
3. Physical geography is the study of physical processes and patterns in the natural environment that shape the surface of the earth and their associated variability over space and time.
4. Physical geography studies the spatial patterns and spatial relationships of environmental components of the globe in regional context, it also studies the causes of regional patterns of such relationships.
5. A field of physical geography including climate and atmosphere, geomorphology, biogeography, hydrology, oceans, Quaternary environmental change, soils, remote sensing and GIS.

The main purpose of studying physical geography is to explain the spatial characteristics of the various natural phenomena associated with geomorphology, climatology, oceanography, pedology, biogeography etc.

1.2 Scope of Physical Geography

It is evident from the foregoing discussion on the nature of physical geography that the detailed consideration of four components of the earth viz. lithosphere, atmosphere, hydrosphere and biosphere are included in physical geography wherein characteristic features of these components are studied spatially and temporally. First the origin age and structure of the interior of the earth, isostasy and evolution of continents and ocean basins are studied in order to understand the characteristic features of the aforesaid four components. The study of forces or movements of the earth both endogenetic (originating from within the earth) and exogenetic (originating from the atmosphere) becomes significant to understand the interactions between these two forces and resultant features. In fact endogenetic forces (termed as constructive forces) coming from within the earth, create reliefs of varying dimensions on the earth’s surface (e.g. mountains, folds, faults, volcanic cones etc.) which provide habitats for living organisms of the biospheric ecosystem on the one hand, and present initial reliefs for the interplay of exogenetic forces originating from the atmosphere termed as destructive forces (denudational processes e.g. fluvial, marine, glacial, aeolian, periglacial etc. processes and weathering agents) on the other hand. The study of evolution of continents and ocean basins and their drifting (continental drift as evidenced by plate tectonics) helps in the understanding of evolution and dispersal of plants and animals.

The characteristics, origin and distribution of constructional reliefs namely mountains, faults, folds etc. are thoroughly investigated. The distribution, characteristics and origin of volcanicity and landforms resulting therefrom are studied as physical features and natural hazards which adversely affect both human being and plants and animals. The study of features resulting from the interactions between endogenetic and exogenetic forces involves the discussion of mode of denudational processes (Weathering and erosion), hetherto termed as geomorphic processes, their mechanism of operation (mechanism of erosion, transportation and deposition by running water-
river, groundwater, sea waves, wind: glacier and periglacial agent) and resultant landforms. The study of hydrospheric component involves the consideration of reliefs of the ocean basins (continental shelves, submarine canyons, continental slope, deep sea plains, ocean deeps etc.); thermal characteristics of ocean water; salinity (composition of seawater, sources and distribution of oceanic salinity); ocean deposits; ocean tides; ocean currents and coral reefs and atolls (their distribution and origin, coral bleaching etc.).

The study of atmospheric component includes the discussion of composition and structure of atmosphere, elements of weather and climate, insolation and heat balance, terrestrial radiation balance and anthropogenic factors causing imbalance, air temperature, air pressure and winds (permanent or planetary winds, seasonal and local winds), characteristics and origin of monsoon, humidity and precipitation, airmasses, frontogenesis, cyclones and anticyclones, world climate etc. The study of biospheric component involves the consideration of components of biosphere (both abiotic and biotic), soil system, ecological production and energy flow in the biospheric ecosystem, circulation of elements in the ecosystem, biogeochemical cycles, evolution, dispersal and extinction of plants and animals, biomes and man, ecosystem stability and man, and atmospheric environment (global radiation balance, ozone depletion, greenhouse effect, and global warming) man and environmental processes, man induced soil erosion and sedimentation, environmental degradation and pollution, extreme events, hazards and disaster, environmental planning and management, global environmental problems and international co-operations.

It is evident from the aforementioned discussion that the scope of physical geography includes the consideration of systematic study of physical environment as well as the study of interactions between man and physical environment. Major changes have taken place in the subject matter and methodology of physical geography due to following factors: (1) Universal desire to make physical geography more meaningful and applicable for human welfare and to integrate it more intimately with human geography in order to redefine and to keep the discipline of geography intact and to make it more relevant to society. (2) More attention of man towards natural hazards and disaster and greater emphasis on the evaluation of adverse impacts of human activities on physical environment and environmental problems resulting therefrom and remedial measures therefor. (3) Greater emphasis on instrumentation and measurement of operation of different geomorphic processes and mathematical analysis of data derived through field and laboratory studies. (4) More attention towards the study of certain aspects of physical geography e.g. ecosystem and ecological stability and instability, hydrology, plate tectonics etc. (5) Recent trends of increasing emphasis on micro-temporal scale (i.e. graded and steady state time scale) in place of macro-temporal scale (i.e., cyclic time involving geological time i.e. millions of years) and on shorter microspatial scale (10 to 100 km2) in place of large or macrospatial scale (megascale, millions of square kilometres) in the study of geomorphic and environmental processes to make such study more relevant to society in order to solve immediate environmental problems.
1.3 Branches of Physical Geography

There are five fields or branches of physical geography varying from geomorphology to biogeography as highlighted below:

**a. Geomorphology:**

It is the science of earth surface processes and landforms. In other words, it is the scientific study of surface involving interpretative description of landforms, their origin and development, and nature and mechanism of geomorphological processes which evolve the landforms. Modern geomorphology also focuses on modeling landform shaping processes to predict both short-term (rapid) changes such as landslides, floods, coastal storm, erosion, and long term (slower) changes, such as soil erosion in agricultural areas or as a result of strip mining.

Geomorphology also has two sub-fields which are fluvial geomorphology, tropical and desert geomorphology. These fields deal with the study of some specific landforms which consist in various environments. One of the common things between these fields is that the fact that these are all united by the core processes which shaped them, which was mainly tectonic processes. The various dynamics and landform history is studied by geomorphology and also predicts the changes which are going to appear because of the combination of field observation, some numeric modeling and physical experiment.

**b. Climatology:**

Climatology is the science that describes and explains the variability of atmospheric conditions (heat and moisture) over space and time. According to Critchfield, climatology is the science which studies the nature of climate, the causes and interpretation of its spatial variations and its association with the elements of natural environment and human activities. In simple words, it is the systematic and regional study of atmospheric conditions i.e. weather and climate. Climatology is concerned with climate change, both in past and future.

Climatology is the study of climatic conditions which are also called as the weather conditions which are studied and averaged over a long period of time. This subject covers both the nature of macro or global and micro or local climatic conditions. The anthropogenic as well as natural influences which occur on them are also studied. The sub-fields which divide different parts of this subject are tropical climatology as well as the paleoclimatology. The climatic study differences are dividing on the basis of the various different regions.

**c. Oceanography:**

The science of hydrosphere i.e. oceans and seas is called oceanography which includes the consideration, description, and analysis of both physical and biological aspects of hydrosphere. It is concerned with the study of various types of Oceanic component and processes related to ocean floor depths, currents, corals, reefs, continental drifts, motion of sea water, wave energy, currents and estuary etc. The study of oceanography has gained much importance during the current times because of the economic and strategic importance of oceans and seas. Today more focus is on applied
oceanography which includes the consideration of delineation, mapping, exploration, utilization and management of marine abiotic as well as biotic resources.

d. Pedology:

Pedology is the study of the distribution of soil types and properties and the processes of soil formation. It is related to both geomorphic processes of rock break up and weathering, and to biological processes of growth, activity and decay of organisms living in the soil. Since both geomorphic and biological processes are influenced by the surface temperature and availability of moisture, broad-scale soil patterns are often related to climate.

e. Biogeography:

Biogeography is the science of the distributions of organisms at varying spatial and temporal scales, as well as the processes that produce these distribution patterns. Alfred Russell Wallace is known as the father of this field's study. Local distribution of plants and animals typically depend on the suitability of the habitat that supports them. In this application biogeography is closely aligned with ecology. Over broader scales and time periods, the migration, evolution and extinction of plants and animals are key processes that determine their spatial distribution patterns. Thus, bio-geographers often seek to reconstruct past patterns of plants and animal communities from fossil evidence of various kinds. There are five main sub fields of biogeography: zoogeography, phytogeography, paleobiography, island biography and phylogeography.

In addition to these five main fields of physical geography, two others are strongly involved with applications of physical geography – water resources and hazards assessment.

1.4 Importance of Physical Geography

It is important to study Physical Geography because it helps us to understand the relationship between man and his physical environment. It tells us how nature nourishes and puts limitations on man. It also helps us to recognize man's impact on the natural environment. Thus, the knowledge of Physical Geography can be used for land use planning and for resource management.

By studying the lithosphere, we are aware of what lies within the earth's crust and hence we are able to understand the Geography of the external landforms. The study of rocks helps us understand the relationship of rocks and landforms and their uses e.g. that softer rocks like clay and shale are worn down easily compared to harder rocks like granite. Rocks also form the basis for soil, vegetation and land use, so we must have a fair knowledge of rocks around us. Knowledge of the earth's movements helps us to understand the modelling of mountains plateaus and plains. We also become aware of the diverse landforms that come into existence because of the various agents of denudation, viz, running water, moving ice, wind, waves etc.

The study of volcanism and earthquakes helps us understand the resultant landforms, inside and outside the’ earth. Finally, the lithosphere has various influences
on man and his activities, e.g. rapids and waterfalls interrupt the navigability of a river, slope of landforms influencing the farming and grazing activities. Silting in the lower courses prevents large steamers anchoring close to the coast, making dredging compulsory. The slope of the land is closely associated with the thickness of soils which in turn influences the vegetation cover, e.g. the found on the soil of Himalayas are poor and thin but in the plains of the Ganga the soil is thick and fertile.

By studying climate and its various elements viz. temperature, pressure, moisture etc. we learn how they are so essential for plants and organisms, how they regulate man's food, clothing, shelter and occupations. Climate influences our physical characteristics, mental alertness and even racial differences. Farmers and their crops are still at the mercy of the climate. A sound knowledge of the atmosphere helps us to avoid or reduce the seriousness of calamities influenced by climate.

Climate influences landforms through the joint processes of weathering and denudation. The main agents of denudation-wind, rain and ice are the direct results of climatic factors. Climate, through its elements of rainfall and temperature, has an influence on vegetation. e.g. the high temperatures and heavy rainfall of equatorial regions are responsible for a luxuriant growth of trees. The Sahara receives scanty rainfall and is barren with only thorny bushes. As the conditions of climate vary, the forests may be evergreen hardwoods or conifers or deciduous. Further the grasslands may have tall grasses like the Savannas or low and rich grasses like the Prairies.

Climate influences soil through the elements of moisture conditions, temperature and wind, e.g. in equatorial areas, due to heavy rainfall, silica is washed away and the soils are heavily leached. The temperature grasslands add rich humus to the soil and make the soil fertile.

By studying the climatic elements of the earth, the earth can be divided into man climatic regions. Each region has approximately the same temperature, wind, rainfall conditions and is therefore capable of producing the same vegetation or supporting the same type of animals, which in turn influence the occupations of the people. In Physical Geography, we study the hydrosphere. Oceans have a tremendous influence on climate. Land and water heat and cool down at different rates that is why temperature and pressure differences are created. Oceans are also a source of humidity to the atmosphere. Places near the coast have an equable climate e.g. Bombay, while places far inland have an extreme climate e.g. Delhi.

The differences of pressure on land and water lead to the formation of winds on a global scale, or periodic winds like the monsoons or land sea breezes. The oceans act as trackless transportation routes and connect every continent. Oceans are a source of food for man, for, they sustain a vast and complex marine life. They constitute a vast reservoir of salt and mineral matter which may be extracted by man.

Finally, it is important to study plant Geography as a part of Physical Geography. It deals with vegetation types i.e. forests, grasslands-and deserts. It provides valuable information regarding different types of forests, their species, areas of growth, and their economic uses. Plant Geography helps us to recognize which forests are valuable, e.g.
the coniferous forests are valuable for their softwood. Plant Geography explains how vegetation influences soil formation, soil fertility, soil erosion, reduction of temperature and increase in rainfall. It also deals with vegetation as the home of animals. It helps us realise how much vegetation cover has been destroyed by man.

The study of Physical Geography is very important in this technological era; it gives us a physical background or base for Human Geography study, urban planning and natural disasters management. Construction of road, building, savage and sanitary waste, water lines are planned according to the slopes. Military strategic planning is influenced by the physical structure of any nation. Physical environment provides resources, and human beings utilise these resources and ensure their economic and cultural development. Accelerated pace of resource utilization with the help of modern technology has created ecological imbalance in the world. Hence, a better understanding of physical environment is absolutely essential for sustainable development.
Atmosphere

The atmosphere is a blanket of gases and suspended liquids and solid entirely envelop the earth.

H. J. Chritchfield

The atmosphere is a mixture of numerous gases. It envelops the earth and extends as far as 9600 km. above the earth’s surface. This gaseous cover of the earth is held around it by gravitational attraction. Like the lithosphere and hydrosphere, the atmosphere too is an integral part of the planet earth and is inseparable from it. About 97 percent of the air is concentrated in the lower 29 km.

According to H. J. Chritchfield ‘the atmosphere is a blanket of gases and suspended liquids and solid entirely envelop the earth’. The atmosphere is act as a great canopy to protect the earth’s surface from the solar radiation.

The atmosphere differs from the lithosphere and the hydrosphere in many respects. Atmosphere is a colourless, odourless and tasteless substance. Besides, it is mobile, elastic and compressible. The most interesting fact about air is that we do not feel its presence unless there is horizontal motion in it. Air in horizontal motion is known as ‘wind’. Although air is not as dense as land or water, it has weight, and the pressure it exerts on the surface is called the atmospheric pressure.

2.1 Composition and Structure of Atmosphere

a. Composition of the Atmosphere:
The atmosphere is a mixture of many gases. In addition, it contains huge numbers of solid and liquid particles, collectively called aerosols. Some of the gases may be regarded as permanent atmospheric components that remain in fixed proportions to the total gas volume. Other constituents vary in quantity from place to place and from time to time. If the suspended particles, water vapor and other variable gases were excluded from the atmosphere, we would find that the dry air is very stable all over the earth up to an altitude of about 80 kilometers.

Two gases, nitrogen and oxygen, make up about 99 per cent of the clean, dry air. The remaining gases are mostly inert and constitute about 1 per cent of the atmosphere. At higher altitudes, the chemical constituents of air change considerably. This layer is known as the heterosphere.

At sea level the following principal gases comprise the dry air; nitrogen, oxygen, argon, carbon dioxide, neon, helium, ozone, hydrogen, krypton, xenon and methane. Out of these gases, argon, neon, helium, krypton and xenon are so inert chemically that they are never found in any chemical compounds. They stand completely alone. Besides these gases, quantities of water vapor and dust particles are also present in the atmosphere. These solid and liquid particles are of great climatic significance. Different constituents of the atmosphere, it may be noted, have got their individual characteristics as briefly discussed below.

a) Oxygen (O2): All living organisms inhale oxygen. No life is possible without it. It is capable of combining with all other elements to form different compounds. It is essential for most combustion. When any substance burns, oxygen is consumed. Oxygen alone constitutes about one-fifth of dry air.

b) Nitrogen (N2): Nitrogen is another important gas of which about 78 percent of the atmosphere’s volume is made up. Nitrogen does not easily enter into chemical union with other substances, but it is an important constituent of many organic compounds. Nitrogen serves mainly as a diluent. It is relatively inactive chemically, though many of its compounds are very active. Its main function in the atmosphere is to regulate combustion by diluting oxygen. It also indirectly helps in oxidation of different kinds.
c) **Carbon dioxide (CO2):** The third important gas is carbon dioxide, which is a product of combustion and constitutes only about 0.03 per cent of the dry air. Green plants, in the process of photosynthesis, extract carbon dioxide from the atmosphere and utilize it. It is exhaled by animals. Being an efficient absorber of heat from the upper atmosphere as well as the earth, carbon dioxide is considered to be of great climatic significance. This gas emits about half of the absorbed heat back to the earth. Thus, it influences the flow of energy through the atmosphere. Carbon dioxide is considered to be a very important factor in the heat energy budget. Its role in the atmosphere and its possible impact on climate cannot be overemphasized. Despite the fact that the proportion of carbon dioxide is relatively constant in the air, its percentage is gradually rising for more than a century. By burning fossil fuels such as coal, oil, and natural gas, we are steadily adding more and more of this gas to our atmosphere. Although about half of this additional carbon dioxide is absorbed by the oceans, or is consumed by plants, the remaining 50 percent is present in the air.

d) **Ozone (O3):** It is found very small quantity in the upper atmosphere. It is less than 0.00005 per cent by volume, and is not uniformly distributed in the atmosphere. The greatest concentrations of ozone are found between about 20 and 25 km, although it is formed at higher levels and transported downward. It is the most efficient absorber of the burning ultraviolet radiation from the sun. In the absence of the ozone layer found in the atmosphere and in the event of the ultraviolet rays reaching the earth’s surface, our planet would have been rendered unfit for human habitation as well as for all living organisms. The ozonosphere protects us from excessive quantities of these deadly rays.

e) **Water Vapour:** Water vapour is one of the most variable gases in the atmosphere, which is present in small amounts, but is nonetheless very important. Water vapour is always present in some proportion in the lower atmosphere. The Water vapour content of air may vary from 0.02 percent by volume in a cold dry climate to nearly 4 percent in the humid tropics. The variations in this percentage over time and place are very important considerations climatically. In addition, it absorbs not only the long wave terrestrial radiation, but also a part of the incoming solar radiation. Water vapour is the source of all clouds and precipitation. The most important as well as the most interesting thing about water vapour is that about 90 percent of it lies below 6 kilometers of the atmosphere.

f) **Dust Particles:** dust particles includes all the solid particles present in air excepting the gases and Water vapour. There is a great variation in the amount of dust over the earth’s surface. Even over the oceans, the air contains hundreds of dust particles per cubic centimeter. Many particles are invisible to the naked eye and are microscopic. They originate from different sources, both natural and man-made. They include sea salts from breaking sea waves, pollen and various organisms lifted by the wind, smoke and soot from fires, tiny sand particles raised from active volcanoes.
b. Structure of the Atmosphere

From the beginning of the 20th century the information of the atmosphere received from when aeroplanes and radio were invented, the knowledge of the upper part of the atmosphere became rather essential. Layer of the shows differences in the properties consist of density, pressure, chemical and electrical properties, and temperature etc. According to Petterssen, the atmosphere is divided into the following more significant spheres, (1) Troposphere (2) Stratosphere (3) Ozonosphere (4) Ionosphere (5) Exosphere

1) Troposphere: The lowermost part of the atmosphere in which we live, in which most clouds form and which is the theatre for weather as we know it, is termed as the troposphere. It contains about 75 per cent of the total gaseous mass of the atmosphere and practically all the moisture and dust particles.

The term troposphere was first suggested by Teisserence de Bort. Troposphere literally means the ‘region of mixing’. It has been derived from the Greek word ‘tropos’ meaning ‘mixing’ or ‘turbulence’.

The average height of this lowermost layer of the atmosphere is placed at about 14 kilometers above sea level. However, its height varies from place to place and from season to season. Under normal conditions, the height of the troposphere at the poles is about 8 kilometers, while at the equator it is about 16 kilometers. Thus, there are marked variations in the height of this layer as between different latitudes.

Troposphere is marked by turbulence and eddies. It is also called the convective region, for all the convective activities cease at the upper limit of the troposphere. Various types of clouds, thunderstorms as well as the cyclones and anticyclones occur in this sphere because of the concentration of almost all the water vapour and aerosols in it.

Another important characteristic of the troposphere is that the wind velocities increase with height and attain the maximum at the top.

The most important feature of the troposphere is that there is a decrease of temperature with increasing elevation at a mean lapse rate of about 6.5° Celsius per kilometer (or 336° F/ 1000 ft.).
The level of change is the tropopause, which also marks the upper boundary of the troposphere. The word tropopause has also been taken from the Greek word which literally means, ‘where the mixing stops’.

(2) **Stratosphere:** The stratosphere begins at the tropopause, which forms its lower boundary. The lower stratosphere is isothermal in character. Above the tropopause no visible weather phenomena ever occur. There is a gradual temperature increase with height beyond 20 kilometers. This region is known as the upper stratosphere. The thickness of the stratosphere is highest at the poles. The upper boundary of the stratosphere is called the stratopause. Above this level there is a steep rise in temperature.

(3) **Ozonosphere (Mesosphere):** There is the maximum concentration of ozone, a vital gas, between 30 and 60 km above the surface of the earth. Because of the concentration of ozone in this layer it is called the ozonosphere. It is made up of three atoms of oxygen while ordinary oxygen is made up of only two. The formation of ozone takes place in the upper stratosphere when an oxygen molecule is broken into two atoms by ultra-violet radiation and the free unstable atoms combine with two other oxygen molecules. This results in the formation of two molecules of ozone which comprise three oxygen atoms each. The ozone layer acts as a filter for the ultra-violet rays of the sun. Because of its inherent quality to absorb short-wave radiation its usefulness to climate cannot be overemphasized. The presence of this layer is undoubtedly a boon to humanity. Harmful ultra-violet radiation in excessive quantity would render men and animals blind. This would also burn man’s skin, increase the incidence of skin cancer, a dreadful disease, and destroy many microscopic forms of life. In addition, it could damage flora on our earth. Because of the preponderance of chemical processes, this layer is also called chemosphere.

(4) **Ionosphere:** Ionosphere, according to Petterssen, lies beyond the ozonosphere at a height of about 60 km above the earth’s surface. At this level the ionization of atmosphere begins to occur. The first knowledge about the existence of this highly ionized layer at such great heights was acquired by means of radio waves. The credit for the discovery of this layer goes to Kennelly and Heaviside.

Layers of the ionosphere: The ionosphere consists of the following ionized layers as following

<table>
<thead>
<tr>
<th>Layer</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-Layer</td>
<td>60-99 km</td>
</tr>
<tr>
<td>E-Layer</td>
<td>90-130 km</td>
</tr>
<tr>
<td>Sporadic E-layer</td>
<td>10 km</td>
</tr>
<tr>
<td>E1-layer</td>
<td>150 km</td>
</tr>
<tr>
<td>F-layer F2 layer</td>
<td>~150-380 km</td>
</tr>
<tr>
<td>G-layer</td>
<td>400 km and above.</td>
</tr>
</tbody>
</table>

D-layer: The D-layer reflects low-frequency radio waves, but absorbs medium-and high-frequency waves. Being closely associated with solar radiation, it disappears as soon as
the sun sets. During increased sun spot activity all medium-and high frequency radio waves stop.

E-layer: The E-layer is also called the Kennelly-Heaviside layer. It reflects the medium-and high-frequency radio waves. It is much better defined than the D-layer. It is produced by ultraviolet photons from the sun interacting with nitrogen and nitrogen molecules. This layer also does not exist night.

Sporadic E-layer: This layer occurs under special, circumstances. It is believed that this sporadic layer is caused by meteors and by the same processes that cause aurora lights. This region is often characterized by high-velocity winds. It affects very high-frequency radio waves.

E2-layer: This region is found above the E-layer and sporadic E-layer. It is produced by ultraviolet photons acting upon oxygen molecules. It appears in day time and vanishes at the sunset.

F1 layer: There is another reflecting layer above the different layers of E-region. There are two sub-layers in this region: F1 and F2. These two sub-layers are collectively known as the “Appleton layer”. The F1 appears during the day, but disappears at night. This layer is especially important in long-distance radio communication. It reflects the medium-and high-frequency radio waves.

F2-layer: Like the F1-layer this layer is very important in long-distance radio transmission. This layer is characterized by diurnal as well as seasonal variability. It appears as directly related to sunspot activity. Its maximum development occurs shortly after local noon and during the middle of winter.

G-layer: This reflecting layer is found above the F2-layer. Its existence came to be known as a result of the latest exploration carried into the upper part of the atmosphere. It is most probably present much of the time, but it may not be detectable since the F-layer reflects all waves reflected by this layer. Because of the interaction of ultraviolet photons with nitrogen atoms, free electrons are produced in the G-layer.

(5) Exosphere: The outermost layer of the earth’s atmosphere is known as the exosphere which lies between 400 and 1000 kilometers. At such a great height the density of atoms in the atmosphere is extremely low. The atmosphere in this region is so rarefied that it resembles a nebula. Hydrogen and helium gases predominate in this outermost region. At the outermost boundary of our atmosphere the kinetic temperatures may reach a fantastically high value of about 5568° Celsius. However, this temperature in its real sense is entirely different from the temperatures at the earth’s surface. If an astronaut inside a satellite orbiting the earth in the exosphere were to take out his hand, it would not feel hot.

2.2 Insolation: Factors affecting on

Insolation

(1) Angle of incidence (2) Duration of sun-shine (3) Solar constant (4) Distance between the earth and the sun (5) Transparency of the atmosphere.
1) Angle of incidence: The altitude of the sun, i.e. the angle between its rays and a tangent to the earth's surface at the point of observation, controls the amount of insolation received at the earth's surface. As the elevation angle decreases, the area over which the radiation is distributed increases. The vertical rays of the sun heat the minimum possible area, but on the contrary, the oblique rays are spread over a relatively larger area, so that the amount of area over which the available solar energy has to be distributed in increased and the energy per unit area on the earth's surface is decreased. In addition, the oblique rays have to traverse a larger distance through the atmosphere before they strike the surface of the earth. The longer their path, the larger the amount of energy lost by various processes of reflection, absorption, and scattering, etc. Thus, it is clear that the larger amount of radiant energy is destroyed in case of slanting rays than in vertical rays.

2) Duration of sunshine: The duration of sunlight hours determines the length of the day, which also affects the amount of solar radiation received at the surface. Undoubtedly, the longer period of sunshine ensures larger supply of radiation which particular area of the earth will receive. Obviously, the latitudes exercise the most dominant control over the duration of sunshine and thereby the length of the day. The latitudinal and monthly variations in the length of days. The inclination of the earth's axis, its parallelism, the earth's rotation and revolution, all these factors combine together to bring about seasonal changes. It is to be remembered that these astronomical factors not only cause differences in the altitude of the sun, but also differences in the length of day from the equator poleward. At the equator the length of days and nights is 12 hours.

<table>
<thead>
<tr>
<th>Latitude</th>
<th>Longest day or night</th>
<th>Latitude</th>
<th>Longest day or night</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12 hours</td>
<td>63.4</td>
<td>20 hours</td>
</tr>
<tr>
<td>17</td>
<td>13 hours</td>
<td>66.5</td>
<td>24 hours</td>
</tr>
<tr>
<td>31</td>
<td>14 hours</td>
<td>67.4</td>
<td>1 month</td>
</tr>
<tr>
<td>41</td>
<td>15 hours</td>
<td>69.8</td>
<td>2 months</td>
</tr>
<tr>
<td>49</td>
<td>16 hours</td>
<td>78.2</td>
<td>4 months</td>
</tr>
<tr>
<td>58.5</td>
<td>18 hours</td>
<td>90.0</td>
<td>6 months</td>
</tr>
</tbody>
</table>

On the autumnal and vernal equinoxes that occur on September 21 and March 21 respectively, the mid-day sun is overhead at the equator. On these days all over the earth the days and nights are equal. On these two days, the maximum amount of insolation is received at the equator, and the amount goes on decreasing towards the poles. But from the winter solstice (December 22) onward the length of day increases in the northern
hemisphere till the summer solstice (June 21). On the contrary, during this period the length of day in the southern hemisphere decreases and the nights are longer. From June 21 to December 22 the length of day in the northern hemisphere decreases, and in the southern hemisphere it increases. In other words, at the summer solstice the northern hemisphere has the longest day and the shortest night. The condition is reversed in the southern hemisphere. On the contrary, at the winter solstice the southern hemisphere has the longest day, and the northern hemisphere has the longest night. At the respective summer solstice, under cloudless skies, a polar area may receive more radiation per 24 hour-day than other latitudes.

3) Solar constant: As the energy emitted by the sun varies, the amount of insolation received at the surface also changes. But the percentage of change in the solar constant is rather negligible. The variations in the solar constant are caused by periodic disturbances and explosions in the solar surface. The sun-spot studies that have been carried so far establish that when the sun-spots appear in larger numbers, the intensity of the solar radiation received at the surface is increased. Naturally, therefore, as the number of sunspots decreases, the quantity of radiation received at the earth’s surface declines. The scientists are of the opinion that the number of sunspots increases or decreases on a regular basis, creating a cycle of 11 years. According to other investigators, there are sunspot cycles of various lengths, some of about 600 years. There may be still longer cycles.

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

5) Transparency of the atmosphere: Transparency of the atmosphere is an important control on the amount of insolation which reaches the earth's surface. Reflection from dust, salt, and smoke particles in the air is an important mechanism for returning shortwave solar radiation to space. Similarly, reflection from cloud tops also depletes the amount of solar radiation that would otherwise be available to the earth. The effect of certain gases, water vapour, and dust particles on reflection, scattering, and absorption is well-known. Obviously, areas with heavy cloudiness and turbid atmosphere will receive lesser amount of radiant energy at the surface. But the transparency of the atmosphere varies with time and place.

2.3 Temperature: Distribution of temperature (Vertical and Horizontal)

a. Vertical Distribution of temperature

Temperature decreases with increasing height in the troposphere but the rate of decrease varies according to seasons, duration of sunshine and location. On an average, the rate of decrease of temperature with increasing altitudes in a stationary column of air with absence of any vertical motion is 6.5°C per 1000 metres. This decrease of temperature is called vertical temperature gradient or normal lapse rate which is 1000 times greater than the horizontal lapse rate (decrease of temperature with increasing latitudes). The decrease of temperature upward in the atmosphere proves the fact that the atmosphere gets heat from the earth's surface through the processes of conduction, radiation and convection. It is, thus, obvious that as the distance from the earth's surface (the source of direct heat energy to the atmosphere) increases (i.e. as the altitude increases) the air temperature decreases. The following are the reasons for decrease of temperature with increasing altitudes in the troposphere.

(i) Heat is transferred to the atmosphere from the earth's surface through the processes of conduction, radiation and convection. Thus, as the altitude increases the amount of heat transported upward decreases. Consequently, every air layer receives less heat than the air layer lying below.

(ii) The air pressure is higher in the lower portion of the atmosphere near the earth's surface because of weight of all the air layers lying above and thus the air density is maximum in the lower atmosphere but it decreases rapidly upward and the air becomes thin.
(iii) The quantity of water vapour, dust particles, water droplets, carbon dioxide etc., which absorb outgoing longwave terrestrial radiation, is more concentrated in the lower portion of the atmosphere and decreases rapidly with increasing altitude. Thus, the temperature of lower atmosphere becomes more than the air layers lying above because of more and more absorption of terrestrial radiation in the lower air layers. In other words, the temperature decreases upward because of decrease of absorption of terrestrial radiation with increasing height in the troposphere.

(iv) It may be pointed out that the decrease of temperature with increasing height is confined to the troposphere only. The height of troposphere is 16 km and 6 km over the equator and the poles respectively but this height also varies in different seasons i.e. it becomes higher in summer than in winter. The upper limit of troposphere is called tropopause.

It is interesting to note that the temperature at tropopause increases from over the equator towards the poles because the height of tropopause decreases from over the equator towards the poles. The height of tropopause during July and January over the equator is 17 km while temperature at the top of tropopause is 70°C. The height of tropopause decreases to 15 km in July and 12.5 km in January over 45°N latitude but the temperature at the top of tropopause increases to 60°C in July and 58°C in January. The height of tropopause further decreases to 10 km in July and 9 km in January over the poles but the temperature increases to 45°C in July and -58°C in January. Upward from tropopause the temperature is reported to increase with increasing height in the stratosphere wherein it becomes 0°C or 32°F at the height of 50 km from sea level. This is the upper limit of the stratosphere and is called stratosphere. Temperature again decreases with increasing height in the mesosphere (50 km-80 km). The temperature becomes -80°C at mesopause, the upper limit of the mesosphere. Beyond mesopause temperature again increases with increasing height in the thermosphere. It is estimated that the temperature at its upper limit (height undecided) becomes 1700°C. It may be pointed out that this temperature cannot be measured by ordinary thermometer because the gases become very light due to very low air density. Sometimes temperature increases with increasing height in the troposphere. In other words, sometime warm air lies over cold air. This phenomenon is called inversion of temperature.

b. Horizontal Distribution of temperature

According to ancient Greek thinkers the globe is divided into three temperature zones on the basis of latitudes e.g. (1) tropical zone. (2) Temperate zone, and (3) Frigid Zone. (1) Tropical zone extends between the tropics of Cancer (23.5°N) and Capricorn (23.5°S). The Sun’s rays are more or less vertical on the equator throughout the year. The remaining areas are also characterized by vertical sun’s rays at least once every year. There is no winter around the equator because of high temperature prevailing throughout the year but as one approaches the tropics of Cancer and Capricorn summer and winter are clearly observed and differentiated.
(2) **Temperate zone** extends between 23.5° and 66.5° latitudes in both the hemispheres. Though the duration of day and night is longer in this zone but it is never more than 24 hours. There are marked seasonal contrasts with the northward and southward (summer and winter solstices) migration of the overhead sun and thus the range of temperature between summers and winters becomes exceptionally very high.

(3) **Frigid zone** extending between 66.5° latitude and the poles in both the hemispheres is characterized by more oblique sun’s rays throughout the year resulting into exceptionally very low temperature. The length of day and night is more than 24 hours. Days and nights are of 6 months duration at the poles. Sun is never vertical and the ground is covered with snow as temperature more or less remains below freezing point.

It may be pointed out that the Greeks gave undue importance to latitudes in determining different temperature zones and overlooked the controls of contrasting nature of continents and oceans in terms of their heating and cooling, prevailing winds, ocean currents, nature of ground surface etc. Taking all these factors in consideration Soupan divided the globe into temperature zones on the basis of isotherms. According to him the outer limit of tropical zone should be determined on the basis of annual isotherm of 68°F (20°C). The boundary between temperate and frigid zones in the northern hemisphere should be demarcated by 50°F (10°C) isotherm of July while January isotherm of 50°F (10°C) should separate temperate zone in the southern hemisphere.

### 2.4 Atmospheric Pressure: Belts and Planetary Winds

**a. Pressure Belts**

The horizontal distribution of air pressure on the globe is studied on the basis of isobars. Air pressure is generally divided in two type’s viz. (1) high pressure, also called as ‘high’ or anticyclone, and (2) low pressure, also called as ‘low’ or cyclone or depression. If we look fit the globe then it appears that there is certain definite system of high and low pressure. If, for generalization, the globe is considered to be homogeneous (either of land or water), then there should be regular and systematic zonal distribution of high and low pressure but the regularity of pressure belts is disturbed due to unequal distribution of land and water on the globe. The pressure belts are discontinued in the northern hemisphere and several centres of pressure belts are developed but the pressure belts are found more or less in regular pattern in the southern hemisphere.

There is no definite trend of distribution of pressure from equator towards the poles. If the air pressure would have been the function of air temperature alone there should have been regular increase of pressure poleward because temperature regularly decreases from the equator towards the poles but this is not the case. There is low pressure near the equator due to high mean annual temperature but the existence of high
pressure belts near the tropics of Cancer and Capricorn cannot be explained on the basis of temperature because the tropics record very high temperature and hence there should have been low pressure if the temperature would have been the only control of air pressure. The air pressure should increase poleward from the tropics of Cancer and Capricorn because there is rapid rate of decrease of temperature poleward but we find low pressure belt near 60° latitude. Again we find high pressure belts near the poles due to exceedingly low temperature throughout the year. It is obvious that pressure belts are not only induced by thermal factor but they are also induced by dynamic factors.

In all, there are seven pressure belts on the globe. On the basis of mode of genesis pressure belts are divided into two broad categories e.g. (1) thermally induced pressure belts (e.g. equatorial low pressure belt and polar high pressure belt), and (2) dynamically induced pressure belts (e.g. subtropical high pressure belt and subpolar low pressure belt).

(1) Equatorial Low Pressure Belt: The equatorial low pressure belt is located on either side of the geographical equator in a zone extending between 5°N and 5°S latitudes but this zone is not stationary because there is seasonal shift of this belt with the northward (summer solstice) and southward (winter solstice migration of the sun). During northern summer this belt extends up to 20°N in Africa and to the north of tropic of Cancer in Asia while during southern summer this low pressure belt shifts to 10° to 20°S latitude. The equatorial low pressure belt is thermally induced because the ground surface is intensely heated during the day due to almost vertical sun’s rays and thus the lowermost layers of air coming in contact with the heated ground surface also gets warmed. Thus, warmed air expands, becomes light, and consequently rises upward causing low pressure. The equatorial low pressure belt represents the zone of convergence of north-east and south-east trade winds. There are light feeble and variable winds within this convergence belt. Because of frequent calm conditions this belt is called a belt of calm or doldrum.

(2) Sub-Tropical High Pressure Belt: Sub-tropical high pressure belt extends between the latitudes of 25°-35° in both the hemispheres. It is important to note that this high pressure belt is not thermally induced
because this zone besides two to three winter months, receives fairly high temperature throughout the year. Thus, this belt owes its origin to the rotation of the earth and sinking and settling down of winds. It is, thus, apparent that the sub-tropical high pressure belt is dynamically induced. The convergence of winds at higher altitude above this zone results in the subsidence of air from higher altitudes. Thus, descent of winds results in the contraction of their volume and ultimately causes high pressure. This is why this zone is characterized by anticyclonic conditions which cause atmospheric stability and aridity. This is one of the reasons for the presence of hot deserts of the world in the western parts of the continents in a zone extending between 25°-35° in both the hemispheres.

This zone of high pressure is called ‘horse latitude’ because of prevalence of frequent calms. In ancient times, the merchants carrying horses in their ships had to throw out some of the horses while passing through this zone of calm in order to lighten their ships. This is why this zone is called horse latitude. It is interesting to note that this zone of high pressure is not a continuous belt but is broken into a number of high pressure centres.

(3) Sub-Polar Low Pressure Belt:
This belt of sub-polar low pressure is located between 60°-65° latitudes in both the hemispheres. The low pressure belt does not appear to be thermally induced because there is low temperature throughout the year and as such there should have been high pressure belt instead of low pressure belt. It is, thus, obvious that this low pressure belt is dynamically produced. In fact, the surface air spreads outward from this zone due to rotation of the earth and low pressure is caused. It may be pointed out that this factor should be more effective at the poles but the effects of the rotation is negated or say overshadowed due to exceptionally low temperature prevailing throughout the year at the poles. The sub-polar low pressure belt is more developed and regular in the southern hemisphere while it is broken in the northern hemisphere because of over dominance of water (oceans) in the former. Instead of regular and continuous belt there are well defined low pressure centres or cells over the oceans in the northern hemisphere e.g. In the neighbourhood of Aleutian Islands in the Pacific Ocean and between Greenland and Iceland in the Atlantic Ocean. It may be noted that due to great contrasts of temperatures of the continents and oceans during northern summer the low pressure belt becomes discontinuous and is found in a few low pressure cells while the temperature contrast between the continents and oceans is much reduced during winter and hence low pressure belt becomes more or less regular and continuous in the northern hemisphere.

(4) Polar high Pressure Belt:
High pressure persists at the poles throughout the year because of prevalence of very low temperature (below freezing point) all the year round. In fact, both the factors, thermal and dynamic, operate at the poles. There is thinning out of layers of air due to diurnal rotation of the earth as the air spreads outward due to this factor but this effect is overshadowed by thermal factor and hence high pressure is produced due to very low temperature. The horizontal distribution of air pressure is represented and studied through isobars for the months of July (to represent pressure conditions during summer
season) and January (to represent air pressure during Winter season in the northern hemisphere) portray the world distribution of air pressure through isobars in July and January respectively. The class interval of isobars is 3 mb.

**b. Planetary Winds.**

The location of the high and low-pressure belt is considered to be stationary on the globe. Consequently, wind blows from high pressure belt to low pressure belt. The direction remain more or less same throughout the year though their areas change seasonally. Thus, such wind called as permanent or planetary winds. These winds include trade winds, westerlies and polar winds.

**(1) Winds In The Tropics:**

Generally, the areas extending between 30°N and 30°S latitudes are included in tropical zone. Formerly, it was believed that trade winds blow from the subtropical high-pressure belts to the equatorial low pressure belt. The north-east and south-east trades converge along the equator and there are upper air antitrades blowing in the opposite directions of the surface trade winds. The weather conditions throughout the tropical zone remain more or less uniform. There is a belt of calm or doldrum characterized by feeble air circulation. The tropical zone is characterized by doldrum, equatorial westerlies, and trade winds.

**a) Doldrum and equatorial westerlies** -

A belt of low pressure, popularly known as equatorial trough of low pressure, extends along the equator within a zone of 5°N and 5°S latitudes. This belt is called the belt claim or doldrum because of light and variable winds. The doldrum is a regular feature all along the equator and characterized by strong convective instability leading to the formation of cumulonimbus clouds and copious rainfall daily. The belt of doldrum shifts northward during summer solstice (when the sun is vertical over the tropic of Cancer, 21 June) and comes back to its normal position
on Sept. 23 and then shifts southward at the time of winter solstice (when the sun is vertical over the tropic of Capricorn, 22 December).

b) Trade winds-
There is more or less regular inflow of winds from subtropical high pressure belts to equatorial low pressure belt. These tropical winds have north-easterly direction in the northern hemisphere while they are south-easterly in the southern hemisphere. These winds are called trade winds because of the fact that they helped the sea merchants in sailing their ships as their (of trade winds) direction remains more or less constant and regular. According to Ferrel’s law (based on coriolis force generated by the rotation of the earth) trade winds are deflected to the right in the northern hemisphere and to the left in the southern hemisphere. There are much variations in the weather conditions in the different parts of trade winds. The poleward parts of the trade winds or eastern sides of the subtropical anticyclones are dry because of strong subsidence of air currents from above. It may be stated that the trade winds are more regular and constant over the oceans than over the lands.

(2) Horse Latitudes and Westerlies
(i) Horse latitudes- The dynamically induced (due to subsidence of air currents) subtropical high pressure belt extends between 30°-35° (25°-35°) latitudes in both the hemispheres. Thus, this belt separates two wind systems viz. trade winds and westerlies. It is also apparent that the subtropical high pressure belt is the source for the origin of trade winds (blowing towards equatorial low pressure belt) and westerlies (blowing towards subpolar low pressure belt) because winds always blow from high pressure to low pressure. The air after being heated near the equator ascends and after blowing in opposite direction to the surface trade winds descends in the latitudinal zone of 30°-35°. Thus, the descent of winds from above causes
high pressure on the surface which in turn causes anticyclonic conditions. This is why the anticyclonic conditions cause atmospheric stability, dry condition and very weak air circulation. Thus, this zone (30°-35°) is characterized by weak and variable winds and calm. This belt of calm is very popularly known as horse latitudes because of the fact that in ancient times the merchants had to throw away some of the horses being carried in the ships in order to lessen the weight so that the ships could be sailed through the calm conditions of these latitudes.

(ii) Westerlies - The permanent wind blowing from the subtropical high pressure belts (30°-35°) to the subpolar low pressure belts (60°-65°) in both the hemispheres are called westerlies. The general direction of the westerlies is S.W. to NE. in the northern hemisphere and N.W. to SE in the southern hemisphere. There is much variation in the weather conditions in their poleward parts where there is convergence of cold and denser polar winds and warms and lighter westerlies. In fact, a cyclonic front, called as polar front, is formed due to two contrasting air masses as referred to above and thus temperate cyclones are originated. These cyclones move along with the westerlies in easterly direction. Thus, the general characteristic features of the westerlies are largely modified due to cyclones and anticyclones associated with them. Because of the dominance of land in the northern hemisphere the westerlies become more complex and complicated and become less effective during summer seasons and more vigorous during winter season. These westerlies bring much precipitation in the western parts of the continents (e.g. north-west European coasts) because they pick up much moisture while passing over the vast stretches of the oceans. The westerlies become more vigorous in the southern hemisphere because of lack of land and dominance of oceans. Their velocity increases southward and they become stormy they are also associated with boisterous gales. The velocity of the westerlies becomes so great that they are called roaring forties between the latitudes of 40°- 50° S, furious fifties 50°S latitude and shrieckng sixties at 60° S latitude.

(3) Polar Winds-
A low pressure belt, produced due to dynamic factor, lies within the latitudinal belt of 60°-65° in both the hemispheres. This belt of low pressure is more persistent in summer season but generally disappears in winter season. The Icelandic and Aleutian low-pressure cells persist throughout the year. There is very high pressure over the poles because of exceedingly low temperature. Thus, winds blow from polar high pressure to subpolar low-pressure cells. These are called polar winds, which are north-easterly in the southern hemisphere and south-easterly in the southern hemisphere.
Lithosphere

Our planet is almost spherical, with a radius of approximately 6400 km (about 4000 mi).

The knowledge of the internal structure and composition of the earth has been remained a matter of great controversy among the geologists and geo physicists. Today, there is a lot of knowledge available about the earth’s interior. The most ambitious human effort to penetrate Earth’s interior was made by the former Soviet Union, which drilled a super-deep research well, named the Kola Well, near Murmansk, Russia. This was an attempt to penetrate the crust and reach the upper mantle. The reported depth of the Kola Well is a little more than 7.5 miles (12 km). The main sources for the study of earth’s interior includes

1. Evidences based on Artificial Sources
   a. Density: The average density of Earth is about 5.52 g/cm³ and the average density of Earth’s crust is about 2.6 to 3.3 g/cm³. This indicates higher density below the crust and because the acceleration due to gravity is quite uniform everywhere therefore mass is distributed uniformly in the form of concentric layers. It is estimated that the relative density of the rocks of the interior part of the earth is about 11 to 13.
   b. Pressure: Pressure in itself is not responsible for the increase in density; rather the core is composed of intrinsically heavy metallic materials of high density.
   c. Temperature: there is a rise of 1°C with every 32 meters of depth. This rate of increase is uniform everywhere on the earth. The temperature at the depth of 50 km should be around 1500°C. It is, therefore, clear that the solid layer of the Earth is a thin film over the otherwise molten material. Evidences based upon temperature indicate that
middle layer exists between 1200 to 2900 km of depth. The lowest layer is considered to be 2900 to 6378 km deep.

d. Meteorites: Meteorites (hitting earth) allow us to determine the density, mineralogy and chemistry of the nickel iron core of bodies having a similar composition to that of the earth.

2. Natural sources

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

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

1. Primary (Longitudinal or Compressional or „P”) waves—to and fro motion of particles in line of the propagation of the ray. These waves can pass through both the solid and the liquid medium
2. Secondary (transverse or distortional or S) waves—particles move at right angles to the rays. These waves cannot pass through the liquid.
3. Surface (Long-Period or ‘L’) waves: Affect only the surface of the earth and covers the longest distance of all seismic waves. It has lower speed than P and S waves but is of most violent and destructive nature. These waves get reflected and refracted while passing through a body having heterogeneous composition and varying density zones at the discontinuities.

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

3.1 Structure of Earth’s interior

The Crust: It is the outermost part of the earth. It is brittle in nature. The thickness of the crust varies under the oceanic and continental areas. The main thickness of oceanic crust is 5 to 8 km and that of continental is around 30 km. The continental crust is thicker in the areas of major mountain systems. It is as much as 70 km thick in the Himalayan region. It is made up of heavier rocks having density of 3 g/cm³. This type of rock found in the oceanic crust is basalt. The mean density of material in oceanic crust is 2.7g/cm³.
The Mantle: The portion of the interior beyond the crust is called the mantle. It is separated from the crust by a boundary, called Moho’s discontinuity. The mantle is about 2900 km thick. It is divided into two sections: the upper mantle and the Lower mantle. These are separated by another boundary, called Repetti discontinuity, after which the rocks of the mantle become soft and pliable due to pressure and heat. The upper portion of the mantle is called asthenosphere. It is the main source of magma that finds its way to the surface during volcanic eruptions. It has a density (3.4 g/cm³) higher than the crust. The crust and upper part of mantle are called lithosphere. Its thickness ranges from 10 to 200 km. The mantle is important in many ways. It accounts for nearly half of the radius of earth, 83 per cent of its volume and 67 per cent of its mass. The dynamic processes which determine the movement of crust plates are powered by the mantle.

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

1. SiAl
Physical Geography (B.A.-I Sem-I)

1. Just below outer sedimentary cover.
   - Composed mainly of granites
   - Density: 2.9 g/cm³
   - 50 to 300 km thick.
   - Rich in silica and aluminium
     (Silicates mainly present are those of sodium, potassium and aluminum.)
   - It forms the continental layer.
     Acidic in nature

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

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

Mechanical Divisions of Earth

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

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

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

Discontinuities:
Many such discontinuities are expressed as follows-
1. Gutenberg discontinuity—Between outer liquid core and the solid mantle
2. Mohorovicic discontinuity—Between crust and mantle.
3. Conrad discontinuity—Between oceanic (Basaltic or SiMa layer) and continental (Granites or SIAL layer) Crust-Up to 30 – 40 km beneath the continents (greater depth in mountainous regions). 10 km deep beneath the oceans.

Willingdon College Sangli
3.2 Wegener’s Theory of Continental Drift

The theory of continental theory is an attempt to explain the present arrangement of continents and ocean basins. Continental drift is the large scale horizontal displacement of continents with respect to each other and with respect to ocean basins during one or more episodes of geological time.

It is worthy to mention here that though the credit for the development of continental drift goes to Alfred Wegener, there were a number of earlier scholars who also talked about continental drift in one way or the other. These scholars were Abraham Ortelius, Sir Francis Bacon, Antonio Snider Pellinerig, F.B Taylor etc.

However the, Alfred Wegener, a German meteorologist and geophysicist is considered by most scientists to be the pioneer of the modern continental drift theory. He presented his ideas in 1912. As Wegener was a meteorologist and geophysicist, he was interested to investigate the relative distribution of land and sea and the climatic anomaly of the past and with this thing in mind he concluded about the drift of continents, which he presented in his book „origin of continents and oceans‟, which was first published in German in the year 1915 and was later translated into English in 1924. As already mentioned, the main theme of Wegener’s theory was based on climatic changes reported in the past history.

Wegener believed on three system of earth’s layers; SIAL, SIMA and NIFE. He believed that SIAL being lighter and uppermost floats over a denser SIMA and NIFE. Assuming on the basis of paleo-climatology, paleo-botany and geology that all the landmasses were united together which he called “Pangaea” surrounded by a huge water body called “panthalassa”. According to Wegener Pangaea started breaking about 300 million years ago and about 200 million years ago (Mesozoic era) first split took place, which divided the continent into two main landmasses namely Laurasia (Europe, Asia, North America and Greenland) in the north and Gondwanaland (South America, Africa, India, Australia and Antarctica) in the south. These two blocks were separated by a long shallow inland sea called sea of Tethys.

According to Wegener, again 70 million years ago, the second drift took place in which the drift was westward and equator ward to southwards. The equator ward drift was due to force of gravity and buoyancy and westwards due to tidal currents because of the earth’s motion. In this drift the centrally located sea of Tethys was filled and the blocks of plates of America drifted westwards and mountain ranges of Rockies and Andes were formed with rubbing of pacific plates. Meanwhile, the peninsular India broke from Gondwanaland and was attracted towards Laurasia being larger one. So the mountain ranges of the Himalayas, Suleiman, Hindukush, Armenia, Atlas and Alps were buckled (raised) from the materials of sea of Tethys whose remaining portion still exists in the form of Mediterranean Sea, Black Sea and Caspian Sea. The Gondwanaland’s split portion of Australia moved towards east forming east mountainous region of Australia. In the same manner, Antarctica also moved southwards forming the present position of continents and ocean basins.
Some of the evidences that are used to support the continental drift theory are the following:

1. Like a jigsaw puzzle, there is a near perfect match of the coastlines of distant continents, such as South America and Africa.
2. Found in continents separated by oceans are identical remains of fossils of certain species of plants and animals.
3. Coal deposits in Antarctica showed that this continent has experienced warm climate. That was the time when it was part of the supercontinent Pangaea.
4. Identical rock formations were found on opposite shores of the Atlantic. This is proof that these shores were once part of the continent.
5. North and South America continue to move away from Europe at the rate of 4 cm/year. India continues to move into Asia at the rate of 5 cm/year. As a consequence, Mount Everest and the Himalayan mountain ranges grow higher by 1 cm/year.

Criticism

One of the main objections to Wegner’s hypothesis stemmed from his inability to provide a driving mechanism for continental drift. Wegner proposed two possible energy sources for drift.

1. The Tidal force/influence of the moon was presumed by Wegner to be strong enough to give the continents a westward motion. However, the prominent Physicist Harold Jeffreys quickly countered with the argument that the tidal friction of the magnitude needed to displace the continents would bring the earth’s rotation to a halt in a matter of few years.
2. Further Wegner proposed that the larger and sturdier continents broke through the oceanic crust, much like icebreakers cut through ice.
3. However no evidence existed to suggest that the ocean floor was weak enough to permit passage of the continents without themselves being appreciably deformed in the process.
4. The hypothesis was criticized largely on grounds of its inability to suggest a satisfactory means of engineering continental movements. It must be conceded that the cumulative evidence supporting the theory of continental drift was massive and the theory was very attractive. If all the points in the theory could be established and an adequate motive force discovered then as Professor Shand has said, “We would have to credit prof. Wegner with the greatest piece of geological synthesis that has ever been accomplished” (1933).
5. Wegner himself in response to his critics said “Scientists still do not appear to understand sufficiently that all earth Sciences must contribute evidence towards unraveling the state of our planet in earlier times, and the truth of the matter can only be reached by combining all this evidence”.

Although most of Wegner’s contemporaries opposed his views, even to the point of openly ridiculing him, a few considered his ideas plausible. Amongst the noted supporter were. Arthur Holmes (1928) contributed to the cause by proposing a plausible driving mechanism for continental drift. Since the time he first proposed, he kept on
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modifying his hypothesis and in his book Physical Geology (1966) he suggested that convection currents operating within the Mantle were responsible for propelling the continents across the globe. Although, even to this day geologists are not in agreement on the exact nature of the driving mechanism, the concept proposed by Holmes is still one of the most appealing. Wegner also in 1929 suggested thermal convection currents.

3.3 Earthquake: Causes and Effects

a. Definition and nature of earthquake.

Earthquakes are the most prominent evidence of present day earth movements. An earthquake is a vibratory motion of the ground surface, ranging from a faint tremor to wild motion capable of shaking buildings apart. In other words, an earthquake is a form of energy of wave motion transmitted through the surface layer of the earth in widening circles from a point of sudden energy release, the focus. The point within the earth where earthquakes are generated is called focus or hypocenter. The point on the earth's surface directly or vertically above the focus is called the epicenter and experience the seismic event first. The science of studying earthquakes is known as seismology. Hence, all the phenomena related to the emergence and manifestation of earthquakes are called seismic. The magnitude or energy released by an earthquake is measured with the help of Richter Scale. Its values range from 1 and 09. Elastic Rebound Theory explains the mode and cause of earthquake.

Earthquake waves or seismic waves

Earthquakes generate pulses of energy called seismic waves. Four types of earthquake waves are found. Three were discovered by R. D Oldham and one later, by Augustas E. H. Love. Basically, they may be divided into two chief kinds of seismic waves:

1. Body waves
2. Surface waves.

1. Body Waves: The fastest seismic waves, move through the earth. Slower surface waves travel along the surface of the earth. Body waves tend to cause the most earth-quake damage. There are two kinds of body waves:

(I). P-waves/ Compressional/ longitudinal waves
(II). S- waves/ Transverse/ Shear waves.

As the waves pass through the earth, they cause particles of rock to move in different ways. Compressional waves push and pull the rock. They cause buildings and other structures to contract and expand. Compressional waves can travel through solids, liquids, or gases. Compressional or longitudinal waves are the fastest seismic waves, and they arrive first at a distant point. For this reason, compressional waves are also called primary (P) waves. They have shortest wavelength among the four. Their velocity is 5 to 12 km/sec. They can travel through liquids (outer core)
and solids (crust, mantle and inner core) but travel faster in denser solid media. These waves are like sound waves and cause any rock in their path to compress and then expand in the same direction as the waves are traveling. Primary waves undergo refraction and reflection at the margin of earth's outer lighter shell and inner dense core.

(II). S- waves/ Transverse/ Shear waves.
Secondary or S waves which are of medium wavelength and high frequency, are also called Shake or Shear waves. Shear waves make rocks bend or slide from side to side, and buildings shake. Shear waves, which travel slower and arrive later, are called secondary (S) waves. Shear waves also called as transverse waves travel through all solid parts of earth but not the liquid part of the core. It is also called distortional wave. Their velocity is about 3 to 4 km/sec.

2. Surface Waves or L- Waves:
These waves are long and slow waves. They are of long wavelength and low frequency. These are confined to the skin of the earth's crust, thereby, causing most of the earthquake structural damage. These waves cover the longest distance of all seismic waves. There are two kinds of surface waves: Love waves and Rayleigh waves.
Love waves, named after A.E.H Love in 1911, travel through the earth's surface horizontally and move the ground from side to side. Typical Love waves travel at about 4.4 kilometers per second.
Rayleigh waves, named after Lord Rayleigh in 1885, make the surface of the earth roll like waves on the ocean. Rayleigh waves, the slowest of the seismic waves, move at about 3.7 kilometers per second. Types of earthquakes on the basis of depth/focus.
Depending on the depth (focus) at which they emerge, earthquakes are classified as:
(i) Surface Earthquake: Earthquakes having a focus at the depth of upto 10 kms are known as surface earthquakes.
(ii) Normal earthquakes: Earthquakes having a focus at the depth of 10 to 70 kms are known as normal earthquakes.
(iii) Intermediate Earthquakes: Their depth /focus ranges from 70 to 300 kms. They accounts for about 18 per cent of the total earthquakes.
(iv) Deep focus earthquakes: Their depth of focus exceeds 300 kms. They are very inconsiderable and are mainly recorded within the confines of Far East. The focus of Deep- Focus earthquakes is placed at 760 km.

Measurement of Earthquakes
There are many scales devised for the measurement of earthquake intensity. Out of these Mercalli and Richter are most well-known.
1. Richter scale: Probably the best-known gauge of earth-quake intensity is the local Richter magnitude scale, developed in 1935 by United States seismologist Charles Francis Richter. This scale, commonly known as the Richter scale, measures the ground motion caused by an earthquake. It is a logarithmic scale that runs from 0
to 9, though no upper limit exists. There are about 10 times as many quakes for every decrease in Richter magnitude by one unit. For example, a magnitude 7 quake is 10 times more powerful than a magnitude 6 quake, 100 times more powerful than a magnitude 5 quake, 1000 times more powerful than a magnitude 4 quake, and so on. Until 1979 an earthquake of magnitude 8.5 was thought to be the most powerful possible; since then, however, improvements in seismic measuring techniques have enabled seismologists to refine the scale, and 9.5 is now considered to be the practical limit. Every increase of one number in magnitude means the energy release of the quake is 32 times greater. For example, an earthquake of magnitude 7.0 releases 32 times as much energy as an earthquake measuring 6.0. The largest earthquake ever recorded on the moment magnitude scale measured 9.5. It was an inter-plate earthquake that occurred along the Pacific coast of Chile in South America in 1960.

2. Mercalli Scale: It is a qualitative scale. Hence it is not considered to be accurate from the point of view of scientific measurement. Its scale is dependent upon the experiences gained by human sensory organs and the devastating effects of the earthquakes. It was introduced in 1800’s by the Italian seismologist Giuseppe Mercalli, measures the intensity of shaking with gradations from I to XII. Intensity I on this scale is defined as an event felt by very few people, whereas intensity XII is a catastrophic event that causes total destruction. Intensities II to III on the Mercalli scale are roughly equal to magnitudes 3 to 4 on the Richter scale, and XI to XII to 8 to 9.

### b. Causes of earthquakes

The earthquakes can be divided into three main types on the basis of cause of generation.

1. **Volcanic Earthquakes**
   These are connected with the processes of volcanism. They develop only in the regions of contemporary volcanic activity. They emerge as a result of deep explosions of gases, emitted from the magma and hydraulic shocks of magma. But there are many places where there are no signs of volcanoes but are visited by earthquakes. Hence, volcanic activity can be considered to be a local cause of volcanic activity. The earthquake caused by Krakatao (1883) and Katmai (1912) were experienced only at a small distance from the volcanic areas.

2. **Denudational Earthquakes**
   They result from the collapses of considerable masses of rocks, mainly in mountainous region. They are also called earthquakes due to collapse. For example earthquakes due to large landslides or sinking of underground karst caves.

3. **Tectonical Earthquakes:**
   Earthquakes belonging to this group are characterized by maximum force and account for 95 per cent of all the earthquakes that are registered. These earthquakes
result due to the displacement or dislocation of individual blocks of lithosphere due to short relaxation of plate.

In other words Earthquakes may arise for a variety of reasons. Some tensional earthquakes clearly arise from faulting. Some others arise due to converging hard lithospheric converging plates. Others may result from tearing of the lithosphere under high pressure.

**Distribution of earthquakes/ seismic zones of the world**

The observation of earthquakes that have been made in course of time has provided an opportunity for the scientists to single out the seismic zones of the world. Earthquakes are mainly felt in the following seismic regions.

(i) **The Circum-Pacific Seismic Belt**

This belt is also called as Ring of Fire and corresponds to approximately 68 per cent of all the earthquakes. It has been found that 80 per cent of shallow, 90 per cent of medium and all the deep focus earthquakes originated in this belt. It includes the western coast of North and South America, the Aleutians, Kamchatka, the Kurilis, Japan, the Philippines and a strip through the East Indies to New Zealand.

(ii) **The Mediterranean or Alpine and Trans Asiatic Belt**

This seismic zone accounts for 21 per cent of all the earthquakes. This belt is characterized by larger earthquakes of shallow origin and some of the intermediate origin. This belt extends along the Alpine mountain system of Europe and North Africa, through Asia Minor and the Caucasus, Iran and Pakistan to the Himalayan mountain system including Tibet, the Pamir and China.

(iii) **The Atlantic Belt**

This belt runs from north to south through the middle of the Atlantic Ocean. It contains mostly the earthquakes of shallow origin. These constitute major fracture zones where the plates diverge and new oceanic crust is being formed by the upwelling of magma on the mid-ocean ridges.

**Earthquake distribution in India**

In India, the earthquake region is connected with the Himalayas. The region follows the junction of Tertiary rocks with the older rocks. The most important earthquake areas of India are

(i) **Zone of maximum Intensity -- The Himalayan Region**

(ii) **Zone of Minimum Intensity -- The Northern Plain Region**

**c. Effects of Earthquake**

Environmental implications of earthquakes

**A. Disadvantages**

(i) Landslides swamps fields and houses in the hilly regions.

(ii) Earthquakes results in emergence and subsidence of land.
Earthquakes cause great damage to buildings, roads, railways, dams, bridges etc. It becomes difficult to send supplies to the victims.

The rivers are dammed. It creates floods which inundates fields, towns etc.

Fires are caused in the areas of earthquakes.

Glaciers are breached and their avalanches scatter to far off places.

Underground water is also affected. Lakes and swamps are created at many places.

The water recedes from the sea ports under the influence of earthquake waves.

**B. Advantages**

- New waterfalls and streams are created on the account of the disturbances of the underground water.
- Due to submergence of sea bottoms, deep gulfs are formed.
- New soil is formed due to breakdown of rocks.
- New mineral areas are uncovered.
- Rivers adopt new courses that are fruitful for agriculture.

### 3.4 Volcano: Causes and effects

The terms volcanoes, mechanism of volcanoes and vulcanicity are more or less synonymous to common man but these have different connotations in geology and geography.

**a. Definition of Volcano**

A volcano is a conical or dome-shaped initial landform that is built from lava emerging through constricted vents in the Earth’s surface. Volcanism, or volcanic activity, constructs lofty cones of imposing mountain ranges as well as huge domes or plateaus of volcanic rock.

‘A volcano is a vent, or opening, usually circular or nearly circular in form, through which heated materials consisting of gases, water, liquid lava and fragments of rocks are ejected from the highly heated interior to the surface of the earth’ (P.G. Worcester, 1948).

According to A. Holmes and U.L. Holmes (1978) a volcano is essentially a fissure or vent, communicating with the interior, from which flows of lava, fountains of incandescent spray or explosive bursts of gases and volcanic ashes are erupted at the surface. On the other hand, ‘the term vulcanicity covers all those processes in which molten rock material or magma rises into the crust or is poured out on its surface, there to solidify as acrystalline or semicrystalline rock’ (S.W. Wooldridge and K.S. Morgan, 1959). Some scientists have also used the term of vulcanism as synonym to the term of vulcanicity.

Volcanic mouth which is connected with the interior part of the earth by a narrow pipe, which is called as volcanic pipe. Volcanic materials of various sorts are ejected through this pipe and the vent situated at the top of the pipe. The enlarged form of the
volcanic vent is known as volcanic crater and caldera. Volcanic materials include lavas, volcanic dusts and ashes, fragmental materials etc.

**Types of Volcanoes:**

There is a wide range of variations in the mode of volcanic eruptions and their periodicity. Thus, volcanoes are classified on the basis of (i) the mode of eruption and (ii) the period of eruption and the nature of their activities.

1. Classification on the Basis of the Mode of Eruptions
   A. Central eruption type or explosive eruption type. (a) Hawaiin type (b) Strombolian type (c) Vulcanian type (d) Peleean type (e) Visuvius type
   B. Fissure eruption type or quiet eruption type (a) Lava hood or lava flow (b) Mud flow (c) Fumaroles

2. Classification on the Basis of Periodicity of Eruptions (a) Active volcanoes (b) Dormant volcanoes (c) Extinct volcanoes

**b. Causes of volcanoes**

The volcanic eruptions are associated with weaker zones of the earth surfaces represented by mountain building at the destructive or convergent plate margin and fracture zones represented by constructive or divergent plate boundaries at the splitting zones of mid-oceanic ridges and the zones of transform faults represented by conservative plate boundaries. The mechanism of vulcanicity (vulcanism) and volcanic eruptions is closely associated with several interconnected processes such as

(i) gradual increase of temperature with increasing depth at the rate of 1°C per 32 m due to heat generated from the disintegration of radioactive elements deep within the earth,

(ii) origin of magma because of lowering of melting point caused by reduction in the pressure of overlying super incumbent load due to fracture caused by splitting of plates and their movement in opposite direction,

(iii) origin of uses and vapour due to heating of water which reaches underground through percolation of rainwater and melt-water (water derived through the melting of ice and snow),

(iv) the ascent of magma forced by enormous volume of gases and vapour and

(v) Finally the occurrence of volcanic eruptions of either violent explosive central type or quiet tissue type depending upon the intensity of gases and vapour and the nature of crustal surface.

Theory of plate tectonics now very well explains the mechanism of volcanism and volcanic eruptions. In fact, volcanic eruptions are very closely associated with the plate boundaries. It may be pointed out that the types of plate movements and plate boundaries also determine the nature and intensity of volcanic eruption. Most of the active fissure volcanoes are found along the mid-oceanic ridges which represent splitting zones of divergent plate boundaries.

Two plates move in opposite directions from the mid-oceanic ridges due to thermal convective currents which are originated in the mantle below the crust (plates). This Splitting and lateral spreading of plates creates fractures and faults (transform faults).
which cause pressure release and lowering of melting point and thus materials of upper mantle lying below the mid-oceanic ridges are melted and move upward as magmas under the impact of enormous volume of accumulated gases and vapour. This rise of magmas along the mid-oceanic ridges (constructive or divergent plate boundaries) causes fissure eruptions of volcanoes and there is constant upwelling of lavas. These lavas are cooled and solidified and are added to the trailing ends of divergent plate boundaries and thus there is constant creation of new basaltic crust.

The volcanic eruptions of Iceland and the islands located along the mid-Atlantic ridge are caused because of sea-floor spreading and divergence of plates. It is obvious that divergent or constructive plate boundaries are always associated with quiet type of fissure flows of lavas because the pressure release of superincumbent load due to divergence of plates and formation of fissures and faults is a slow and gradual process. It is apparent from the above discussion that the mid-oceanic ridges, representing splitting zones are associated with active volcanoes wherein the supply of lava comes from the upper mantle just below the ridge because of differential melting of the rocks into tholeiitic basalts.

Since there is constant supply of basaltic lavas from below the mid-oceanic ridges and hence the volcanoes are active near the ridges but the supply of lavas decreases with increasing distance from the mid-oceanic ridges and therefore the volcanoes become inactive, dormant and extinct depending on their distances from the source of lava supply e.g. mid-oceanic ridges. This fact has been validated on the basis of the study of the basaltic floor of the Atlantic Ocean and the lavas of several islands. It has been found that the islands nearer to the mid-Atlantic Ridge have younger lavas whereas the islands away from the ridge have older lavas. For example, the lavas of Azores islands situated on either side of the mid-Atlantic Ridge are 4 million years old whereas the lavas of Cape Verde Illustration of constructive (divergent) and destructive (convergent) boundaries and their relationship with Island, located far away from the said ridge, are 120 million years old. Destructive or convergent plate boundaries are associated with explosive type of volcanic eruptions. When two convergent plates collide along Benioff zone (subduction zone), comparatively heavier plate margin (boundary) is subducted beneath comparatively lighter plate boundary. The subducted plate margin, after reaching a depth of 100 km or more in the upper mantle, is melted and thus magma is formed. This magma is forced to ascend by the enormous volume of accumulated explosive gases and the magma appears as violent volcanic eruption on the earth’s surface. Such type of volcanic eruption is very common along the destructive or convergent plate boundaries which represent the volcanoes of the Circum-Pacific Belt and the Mid-Continental Belt. The volcanoes of the island arcs and festoons (off the east coast of Asia) are caused due to subduction of oceanic crust (plate) say Pacific plate below the continental plate, say Asiatic plate near Japan Trench.

c. Effects of Volcanic Eruption

Volcanic eruptions cause heavy damage to human lifes and property through advancing hot lavas and fallout of volcanic materials; destruction to human structures
such as buildings, factories, roads, rails, airports, dams and reservoirs through hot lavas and fires caused by hot lavas; floods in the rivers and climatic changes. A few of the severe damages wrought by volcanic eruptions may be summarized as given below.

(1) Huge volumes of hot and liquid lavas moving at considerably fast speed (recorded speed is 48 km per hour) bury human structures, kill people and animals, destroy agricultural farms and pastures, plug rivers and lakes, burn and destroy forest etc. The great eruption of Mt. Loa on Hawaii poured out such a huge volume of lavas that these covered a distance of 53 km down the slope. Enormous Laki Lava flow of 1783 A.D. travelled a distance of 350 km engulfing two churches, 15 agricultural farms and killing 24 per cent of the total population of Iceland. The cases of Mt. Pelee eruption of 1902 in Martinique Island (in Caribbean Sea) (total death 28,000) and St. Helens eruption of 1980 (Washington, USA) are representative examples of damages done by lava movement. The thick covers of green and dense forests on the flanks of Mt. St. Helens were completely destroyed due to severe forest fires kindled by hot lavas.

(2) Fallout of immense quantity of volcanic materials including fragmental materials (pyroclastic materials), dusts and ashes, smokes etc. covers large ground surface and thus destroys crops, vegetation and buildings, disrupts and diverts natural drainage systems, creates health hazards due to poisonous gases emitted during the eruption, and causes killer acid rains. (3) All types of volcanic eruptions, if not predicted well in advance, cause tremendous losses to precious human lives. Sudden eruption of violent and explosive type through central pipe does not give any time to human beings to evacuate themselves and thus to save themselves from the clutches of death looming large over them. Sudden eruption of Mt. Pelee on the Island of Martinique, West Indies in the Caribbean Sea, on May 8, 1902 destroyed the whole of St. Pierre town and killed all the 28,000 inhabitants leaving behind only two survivors to mourn the sad demise of their brethren. The heavy rainfall, associated with volcanic eruptions, mixing with falling volcanic dusts and ashes causes enormous mudflow or ‘lahar’ on the steep slopes of volcanic cones which causes sudden deaths of human beings. For example, great mud flow created on the steep slopes of Kelut volcano in Japan in the year 1919 killed 5,500 people.

(4) Earthquakes caused before and after the volcanic eruptions generate destructive tsunamis seismic waves which create most destructive and disastrous sea waves causing innumerable deaths of human beings in the affected coastal areas. Only the example of Krakatoa in 1883 would be sufficient enough to demonstrate the disastrous impact of tsunamis which generated enormous sea waves of 30 to 40 m height which killed 36,000 people in the coastal areas of Java and Sumatra.

(5) Volcanic eruptions also change the radiation balance of the earth and the atmosphere and thus help in causing climatic changes. Greater concentration of volcanic dusts and ashes in the sky reduces the amount of insolation reaching the earth’s surface as they scatter and reflect some amount of incoming shortwave solar radiation. Dust veils, on the other hand, do not hinder in the loss of heat of the earth’s surface through outgoing longwave terrestrial radiation. The ejection of nearly 20 cubic kilometres of
fragmental materials, dusts and ashes up to the height of 23 km in the sky during the violent eruption of Krakatoa volcano on August 27, 1883 formed a thick dust veil in the stratosphere which caused a global decrease of solar radiation received at the earth’s surface by 10 to 20 per cent.

(6) A group of scientists believes that volcanic eruptions and fallout of dusts and ashes cause mass extinction of a few species of animals. Based on this hypothesis the mass extinction of dinosaurs about 60 million years ago has been related to increased worldwide volcanic activity. Acid rains accompanied by volcanic eruptions cause large-scale destruction of plants and animals.

Numerous types of landforms are created due to cooling and solidification of magmas below the earth’s surface and lavas at the earth’s surface and due to accumulation of fragmental materials, dusts and ashes with lavas such as different types of volcanic cones. The cones and craters are not always permanent landforms because they are changed or modified during every successive eruption. Explosive type of volcanic eruptions helps in the formation of several types of volcanic cones whereas fissure flows result in the formation of lava plateaux and lava plains due to accumulation of thick layers of basaltic lavas over extensive areas. The topographic features produced by the entire process of vulcanicity are grouped into two broad categories viz. (i) extrusive topography and (ii) intrusive topography. Fig. 9.6 depicts major characteristic volcanic landforms.

(i) Extrusive Volcanic Topography (i) From Explosive Type of Eruptions (a) Elevated forms. e.g. volcanic cones (b) Depressed form. e.g. craters and calderas (ii) From Fissure Eruptions (a) Lava plateaux and domes (b) Lava plains

(2) Intrusive Volcanic Topography (i) intrusive lava domes, (ii) batholiths, (iii) laccoliths, (iv) phacoliths, (v) lopoliths, (vi) ‘ills, (vii) dikes, (viii) volcanic plugs and stocks etc.
Temperature, air, water etc. soften the rocks of earth’s surface. After sometime the outer surface of the rock is covered by the soften rock mixture. It happens in two phases – (i) Disintegration through physical action & (ii) Decomposition through chemical action which softens the outer hard cover of the rock. The process of forming softened mixture over a hard rock is called weathering. Weathering is the mechanical fracturing and chemical decomposition of rocks, in situ, by natural agents at the surface of the earth (SPARKS).

The hard and solid rock on which weathering takes place is called Bed rock. The softened and loose rock mixture formed on the bed rock due to weathering is called Regolith.

Types of Weathering

According to physical and chemical processes, weathering can be divided into two types

1. Physical weathering
2. Chemical weathering

The importance of physical and chemical weathering depends upon the nature of climate. Physical weathering becomes important in arid climate while chemical weathering is important in hot and humid climate.

1. Physical weathering:

Though the main factor of physical weathering is temperature change, yet other factors like pressure release, freeze, gravity and biological action help a lot in this process.

i) Temperature Change: The rocks are bad conductors of heat and expand on heating in the day but contract on cooling in the night. A pressure develop on the rocks due to continuous expansion and contraction. It produces cracks and joints on the rocks. For example granite rock with a diameter of 30.48 meters when heated and temperature raised by 65.5 degree Celsius, its diameter is increased by 2.54 cm.

Most of the sedimentary and igneous rocks are composed of different minerals. Their expansion is different on account of different specific heats, colours etc. Due to the different expansion of the constituents of rocks, small fissures, fractures etc. are produced into rocks which help in the disintegration of the rocks.

ii) Pressure release: Many igneous and metamorphic rocks crystalline deep in the interior under the combined influence of high pressure and temperature. When the rocks above them are eroded away, the rocks exposed are released from the pressure. Due to pressure release, cracks are produced in the rocks and exfoliation (peeling off thin flakes from the rock) starts.

iii) Freeze thaw: in cold countries, water in the day enters the cracks, fissures and holes in the rocks. The water freeze in the night and its volume increase by 1/11 times. This exert a huge pressure on rocks and weaken them.

iv) Gravity: Many rocks which have large joints disintegrate on account of gravity. Though the effect of gravity is weak, yet its action in breaking down the cracking rocks is not insignificant.

v) Biological action: Vegetation and animals are helpful in the
disintegration of rocks. The roots of plants and trees enter the cracks and fissures of the rocks and loosen the rocks from inside.

Animals also go on wearing away rocks.

2. Chemical weathering: The part of the atmosphere in contact with the earth’s surface contain excess of oxygen, carbon dioxide and water vapour. Oxygen and carbon dioxide become very active in the presence of water and water vapour. The following are the main processes which constitute chemical weathering:-

i) Oxidation: The oxygen of the atmosphere reacts with minerals in the presence of water. For example the iron compound change from ferrous to ferric state (red brown). Clay as long as is submerged in water appear blue as it has iron in ferric state. When the clay is taken out of water, the ferric iron of clay is converted into ferric state and the clay becomes red-brown. When pyrites are acted upon by water, sulphuric acid is produced which start dissolving the pyrites.

ii) Carbonation: ordinary water dissolve calcium carbonate and magnesium carbonate of rocks but when carbon dioxide from atmosphere or rain water comes in contact with them, they are converted to bicarbonates of calcium and magnesium. The limestone, marble and gypsum dissolve in water.

iii) Hydration: It is the process when minerals incorporate water into their molecular structure. Hydration causes swelling thus helps in the crumbling of coarse grained igneous rocks. When calcium carbonate is hydrated it becomes gypsum. When carbon dioxide is dissolved in water, the chemical action takes place at a fast speed. Feldspar mineral through hydration is converted into Kaolin.

iv) Desilication: The separation of silica from the rocks is called desilication. The running water separates silica from granite. Due to excess silica separation, the rock is readily disintegrated. Silica in the form of Quartz is very hard. If there is silica in sedimentary rocks, the latter becomes harder than even igneous rocks but these rocks are readily disintegrated with the separation of silica.

v) Solution: The rain water is able to dissolve certain minerals and leach the soil. Through this process many minerals are washed out of the soil and rocks so that their chemical composition changes. Soluble rock forming minerals like nitrates, sulphates, and potassium etc. are affected by this process. So, these minerals are easily leached out without leaving any residue in rainy climates and accumulate in dry regions. Minerals like calcium carbonate and calcium magnesium bicarbonate present in lime stones are soluble in water containing carbonic acid (formed with the addition of carbon dioxide in water), and are carried away in water as solution. Carbon dioxide produced by decaying organic matter along with soil water greatly aids in this reaction. Common salt (sodium chloride) is also a rock forming mineral and is susceptible to this process of solution.

Factors affecting weathering

The various factors which affect weathering are the nature of rock, climate and time. Weathering is a complex process to understand because many factors act in combination but it is necessary to understand the nature of various factors.
i. Nature of rocks: the rock may be hard or soft, but we have to see whether the rock is porous, soluble and traversed by planes of weakness. Stability of the minerals that constitute the rocks has also to be taken into account. The exposure of rock also fall within the same category. The strength of a particular rock structure, its durability and power of resistance depend upon massiveness of rock, humid climates. In equatorial regions there is high temperature as well as high humidity. Chemical weathering is definitely most important in this region. Rocks as deep as 62 meters from the surface have been found to be decaying. The carbon dioxide from air and nitric acid from thunder of clouds help in the chemical weathering of rocks.

iii. Time: Weathering increases with time but weathering can decrease if the regolith deposited on the rocks is not removed. Davis thinks that the regolith deposited on bed rocks acts as a security layer and almost stops the weathering process. This conclusion may be correct for physical weathering but the same cannot be said for chemical weathering which is not stopped by regolith layer. Ordinary water and acidic water reach the bed rock through regolith and chemical weathering starts.
Denudation

Denudation is continuing process of wearing away earth surface material.

In geography, denudation involves the processes that cause the wearing away of the Earth's surface by moving water, by ice, by wind and by waves, leading to a reduction in elevation and in relief of landforms and of landscapes. Endogenous processes such as volcanoes, earthquakes, and plate tectonics uplift and expose continental crust to the exogenous processes of weathering, of erosion, and of mass wasting.

4.1 Weathering:

Temperature, air, water etc. soften the rocks of earth’s surface. After sometime the outer surface of the rock is covered by the soften rock mixture. It happens in two phases – (i) Disintegration through physical action & (ii) Decomposition through chemical action which softens the outer hard cover of the rock. The process of forming softened mixture over a hard rock is called weathering. Weathering is the mechanical fracturing and chemical decomposition of rocks, in situ, by natural agents at the surface of the earth (SPARKS).

The hard and solid rock on which weathering takes place is called Bed rock. The softened and loose rock mixture formed on the bed rock due to weathering is called Regolith.

Types of Weathering

According to physical and chemical processes, weathering can be divided into two types
1. Physical weathering
2. Chemical weathering

The importance of physical and chemical weathering depends upon the nature of climate. Physical weathering becomes important in arid climate while chemical weathering is important in hot and humid climate.

1. Physical weathering:

Though the main factor of physical weathering is temperature change, yet other factors like pressure release, freeze, gravity and biological action help a lot in this process.

i) Temperature Change: The rocks are bad conductors of heat and expend on heating in the day but contract on cooling in the night. A pressure develop on the rocks due to continuous expansion and contraction. It produces cracks and joints on the rocks. For example granite rock with a diameter of 30.48 meters when heated and temperature raised by 65.5 degree Celsius, its diameter is increased by 2.54 cm.

Most of the sedimentary and igneous rocks are composed of different minerals. Their expansion is different on account of different specific heats, colours etc. Due to the different expansion of the constituents of rocks, small fissures, fractures etc. are produced into rocks which help in the disintegration of the rocks.

ii) Pressure release: Many igneous and metamorphic rocks crystalline deep in the interior under the combined influence of high pressure and temperature. When the rocks above them are eroded away, the rocks exposed are released from the pressure. Due to pressure release, cracks are produced in the rocks and exfoliation (peeling off thin flakes from the rock) starts.

iii) Freeze thaw: in cold countries, water in the day enters the cracks, fissures and holes in the rocks. The water freeze in the night and its volume increase by $1/11$ times. This exert a huge pressure on rocks and weaken them.

iv) Gravity: Many rocks which have large joints disintegrate on account of gravity. Though the effect of gravity is weak, yet its action in breaking down the cracking rocks is not insignificant. v) Biological action: Vegetation and animals are helpful in the disintegration of rocks. The roots of plants and trees enter the cracks and fissures of the rocks and loosen the rocks from inside. Animals also go on wearing away rocks.

2. Chemical weathering:
The part of the atmosphere in contact with the earth’s surface contain excess of oxygen, carbon dioxide and water vapour. Oxygen and carbon dioxide become very active in the presence of water and water vapour. The following are the main processes which constitute chemical weathering

i) Oxidation: The oxygen of the atmosphere reacts with minerals in the presence of water. For example, the iron compound change from ferrous to ferric state (red brown).
Clay as long as is submerged in water appear blue as it has iron in ferric state. When the clay is taken out of water, the ferric iron of clay is converted into ferric state and the clay becomes red-brown. When pyrites are acted upon by water, sulphuric acid is produced which start dissolving the pyrites.

Oxidation occurs when an atom or an ion loses an electron, increasing its positive charge or decreasing its negative charge. It involves oxygen combining with a substance. Oxygen dissolved in water is a prevalent oxidizing agent in the environment. Oxidation weathering chiefly affects minerals containing iron, though such elements as manganese, sulphur, and titanium may also be oxidized. The reaction for iron, which occurs mainly when oxygen dissolved in water comes into contact with iron-containing minerals, is written:

\[ 4\text{Fe}^2+ + 3\text{O}_2 + 2\text{e} \rightarrow 2\text{Fe}_2\text{O}_3 \quad [\text{e} = \text{electron}] \]

Alternatively, the ferrous iron, \( \text{Fe}^2+ \), which occurs in most rock-forming minerals, may be converted to its ferric form, \( \text{Fe}^3+ \), upsetting the neutral charge of the crystal lattice, sometimes causing it to collapse and making the mineral more prone to chemical attack. If soil or rock becomes saturated with stagnant water, it becomes oxygen-deficient and, with the aid of anaerobic bacteria, reduction occurs.

**ii) Carbonation:**

Carbonation is the formation of carbonates, which are the salts of carbonic acid (H\(_2\)CO\(_3\)). Carbon dioxide dissolves in natural waters to form carbonic acid. The reversible reaction combines water with carbon dioxide to form carbonic acid, which then dissociates into a hydrogen ion and a bicarbonate ion. Carbonic acid attacks minerals, forming carbonates. Carbonation dominates the weathering of calcareous rocks (limestones and dolomites) where the main mineral is calcite or calcium carbonate (CaCO\(_3\)). Calcite reacts with carbonic acid to form calcium hydrogen carbonate (Ca(HCO\(_3\))\(_2\)) that, unlike calcite, is readily dissolved in water. This is why some limestones are so prone to solution. The reversible reactions between carbon dioxide, water, and calcium carbonate are complex. In essence, the process may be written:

\[ \text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2 \Leftrightarrow \text{Ca}^{2+} + 2\text{HCO}_3^- \]

This formula summarizes a sequence of events starting with dissolved carbon dioxide (from the air) reacting speedily with water to produce carbonic acid, which is always in an ionic state:

\[ \text{CO}_2 + \text{H}_2\text{O} \Leftrightarrow \text{H}^+ + \text{HCO}_3^- \]

Carbonate ions from the dissolved limestone react at once with the hydrogen ions to produce bicarbonate ions:

\[ \text{CO}_3^{2-} + \text{H}^+ \Leftrightarrow \text{HCO}_3^- \]
This reaction upsets the chemical equilibrium in the system, more limestone goes into solution to compensate, and more dissolved carbon dioxide reacts with the water to make more carbonic acid. The process raises the concentration by about 8 mg/l, but it also brings the carbon dioxide partial pressure of the air (a measure of the amount of carbon dioxide in a unit volume of air) and in the water into disequilibrium. In response, carbon dioxide diffuses from the air to the water, which enables further solution of limestone through the chain of reactions. Diffusion of carbon dioxide through water is a slow process compared with the earlier reactions and sets the limit for limestone solution rates. Interestingly, the rate of reaction between carbonic acid and calcite increases with temperature, but the equilibrium solubility of carbon dioxide decreases with temperature. For this reason, high concentrations of carbonic acid may occur in cold regions, even though carbon dioxide is produced at a slow rate by organisms in such environments. Carbonation is a step in the complex weathering of many other minerals, such as in the hydrolysis of feldspar.

iii) Hydration: It is the process when minerals incorporate water into their molecular structure. Hydration causes swelling thus helps in the crumbling of coarse grained igneous rocks. When calcium carbonate is hydrated it becomes gypsum. When carbon dioxide is dissolved in water, the chemical action takes place at a fast speed. Feldspar mineral through hydration is converted into Kaolin.

iv) Desilication: The separation of silica from the rocks is called desilication. The running water separates silica from granite. Due to excess silica separation, the rock is readily disintegrated. Silica in the form of Quartz is very hard. If there is silica in sedimentary rocks, the latter becomes harder than even igneous rocks but these rocks are readily disintegrated with the separation of silica.

v) Solution: The rain water is able to dissolve certain minerals and leach the soil. Through this process many minerals are washed out of the soil and rocks so that their chemical composition changes. Soluble rock forming minerals like nitrates, sulphates, and potassium etc. are affected by this process. So, these minerals are easily leached out without leaving any residue in rainy climates and accumulate in dry regions. Minerals like calcium carbonate and calcium magnesium bicarbonate present in lime stones are soluble in water containing carbonic acid (formed with the addition of carbon dioxide in water), and are carried away in water as solution. Carbon dioxide produced by decaying organic matter along with soil water greatly aids in this reaction. Common salt (sodium chloride) is also a rock forming mineral and is susceptible to this process of solution.

VI) Hydrolysis: Generally, hydrolysis is the main process of chemical weathering and can completely decompose or drastically modify susceptible primary minerals in rocks. In hydrolysis, water splits into hydrogen cations (H+) and hydroxyl anions (OH–) and reacts directly with silicate minerals in rocks and soils. The hydrogen ion is exchanged with a metal cation of the silicate minerals, commonly potassium (K+), sodium (Na+),
calcium (Ca2+), or magnesium (Mg2+). The released cation then combines with the hydroxyl anion. The reaction for the hydrolysis of orthoclase, which has the chemical formula KAlSi3O8, is as follows:

$$2\text{KAlSi}_3\text{O}_8 + 2\text{H}^+ + 2\text{OH}^- \rightarrow 2\text{HAlSi}_3\text{O}_8 + 2\text{KOH}$$

So, the orthoclase is converted to aluminosilicic acid, HAlSi3O8, and potassium hydroxide, KOH. The aluminosilicic acid and potassium hydroxide are unstable and react further.

**Factors affecting weathering**

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**i. Nature of rocks:**
The rock may be hard or soft, but we have to see whether the rock is porous, soluble and traversed by planes of weakness. Stability of the minerals that constitute the rocks has also to be taken into account. The exposure of rock also fall within the same category. The strength of a particular rock structure, its durability and power of resistance depend upon massiveness of rock, humid climates.

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In equatorial regions there is high temperature as well as high humidity. Chemical weathering is definitely most important in this region. Rocks as deep as 62 meters from the surface have been found to be decaying. The carbon dioxide from air and nitric acid from thunder of clouds help in the chemical weathering of rocks.

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4.2 Davis Concept of Cycle of Erosion

The ‘geographical cycle’, expounded by William Morris Davis, was the first modern theory of landscape evolution (e.g. Davis 1889, 1899, 1909). It assumed that uplift takes place quickly. Geomorphic processes, without further complications from tectonic movements, then gradually wear down the raw topography. Furthermore, slopes within landscapes decline through time – maximum slope angles slowly lessen (though few field studies have substantiated this claim). So, topography is reduced, little by little, to an extensive flat region close to base level a peneplain. The peneplain may contain occasional hills, called monadnocks after Mount Monadnock in New, USA, which are local erosional remnants, standing conspicuously above the general level. The reduction process creates a time sequence of landforms that progress through the stages of youth, maturity, and old age. However, these terms, borrowed from biology, are misleading and much censured (e.g. Ollier 1967; Ollier and Pain 1996, 204–5). The ‘geographical cycle’ was designed to account for the development of humid temperate landforms produced by pro-longed wearing down of uplifted rocks offering uniform resistance to erosion. It was extended to other landforms, including arid landscapes, glacial landscapes, periglacial landscapes, to landforms produced by shore processes, and to karst landscapes. William Morris Davis’s ‘geographical cycle’ – in which landscapes are seen to evolve through stages of youth, maturity, and old age – must be regarded as a classic work, even if it has been superseded. Its appeal seems to have lain in its theoretical tenor and in its simplicity (Chorley 1965). It had an all-pervasive influence on geomorphological thought and spawned the once highly influential field of denudation chronology.
Fluvial erosion and transport Streams are powerful geomorphic agents capable of eroding, carrying, and depositing sediment. Stream power is the capacity of a stream to do work. It may be expressed as:

\[ \Omega = \rho gQs \]

where \( \Omega \) (omega) is stream power per unit length stream channel, \( \rho \) (rho) is water density, \( Q \) is stream discharge, and \( s \) is the channel slope. It defines the rate at which potential energy, which is the product of the weight of water, \( mg \) (mass, \( m \), times gravitational acceleration, \( g \)), and its height above a given datum, \( h \), is expended per unit length of channel. In other words, stream power is the rate at which a stream works to transport sediment, overcome frictional resistance, and generate heat. It increases with increasing discharge and increasing channel slope.

**Stream load**

All the material carried by a stream is its load. The total load consists of the dissolved load (solutes), the suspended load (grains small enough to be suspended in the water), and the bed load (grains too large to be suspended for very long under normal flow conditions). In detail, the three components of stream load are as follows:

1. The dissolved load or solute load comprises ions and molecules derived from chemical weathering plus some dissolved organic substances. Its composition depends upon several environmental factors, including climate, geology, topography, and vegetation. Rivers fed by water that has passed through swamps, bogs, and marshes are especially rich in dissolved organic substances. River waters draining large basins tend to have a similar chemical composition, with bicarbonate, sulphate, chloride, calcium, and sodium being the dominant ions.

2. The suspended load consists of solid particles, mostly silts and clays, that are small enough and light enough to be supported by turbulence and vortices in the water. Sand is lifted by strong currents, and small gravel can be suspended for a short while during floods. The suspended load reduces the inner turbulence of the stream water, so diminishing frictional losses and making the stream more efficient. Most of the suspended load is carried near the stream bed, and the concentrations become lower in moving towards the water surface.

3. The bed load or traction load consists of gravel, cobbles, and boulders, which are rolled or dragged along the channel bed by traction. If the current is very strong, they may be bounced along in short jumps by saltation. Sand may be part of the bed load or part of the suspended load, depending on the flow conditions. The bed load moves more slowly than the water flows as the grains are moved fitfully. The particles may move singly or in groups by rolling and sliding. Once in motion, large grains move more easily and faster than small ones, and rounder particles move more readily than flat or angular ones. A stream’s competence is defined as the biggest size of grain that a stream can move in traction as bed load. Its capacity is defined as the maximum amount of debris that it can carry in traction as bed load.
Stream erosion and transport Streams may attack their channels and beds by corrosion, corrasion, and cavitation. Corrosion is the chemical weathering of bed and bank materials in contact with the stream water. Corrasion or abrasion is the wearing away of surfaces over which the water flows by the impact or grinding action of particles moving with the water body.

**4.3 Erosional Landforms of River**

a) **Valleys**
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 valley, gorge, canyon, etc. can be recognised.

b) **Gorge**: A gorge is a deep valley with very steep to straight sides and a gorge is almost equal in width at its top as well as its bottom.

c) **Canyon**: A canyon is characterised by steep step-like side slopes and may be as deep as a gorge. A canyon is wider at its top than at its bottom. In fact, a canyon is a variant of gorge. Valley types depend upon the type and structure of rocks in which they form. For example, canyons commonly form in horizontal bedded sedimentary rocks and gorges form in hard rocks.

d) **Waterfall**: Waterfall or simply fall are caused of sudden descents or abrupt break in the longitudinal course of river due to several factors such as variation in relative resistant of rocks, relative differences in topographic relief, fall in sea-level and related rejuvenation etc. A vertical drop of water of enormous volume from a great height in long profile of river. Important waterfalls of the world

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<th>location</th>
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<tr>
<td>Jog</td>
<td>253</td>
<td>Karnataka</td>
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</table>

e) **Rapid**: Rapids are of much smaller dimension than waterfalls. Generally, they are found upstream from the main falls but they are also found independently. Ghodchinmalaki Rapid on Malprabha River near Gokak, Karnataka is good example of the rapids developed in sandstone topography.

d) **Potholes and Plunge Pools**
Over the rocky beds of hill-streams more or less circular depressions called potholes form because of stream erosion aided by the abrasion of rock fragments. Once a small and shallow depression forms, pebbles and boulders get collected in those depressions and get rotated by flowing water and consequently the depressions grow in dimensions. A series of such depressions eventually join and the stream valley gets deepened. At the foot of waterfalls also, large potholes, quite deep and wide, form 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. These pools also help in the deepening of valleys. Waterfalls are also transitory like any other landform and will recede gradually and bring the floor of the valley above waterfalls to the level below.
c) Incised or Entrenched Meanders
In streams that flow rapidly over steep gradients, normally erosion is concentrated on the bottom of the stream channel. Also, in the case of steep gradient streams, lateral erosion on the sides of the valleys is not much when compared to the streams flowing on low and gentle slopes. Because of active lateral erosion, streams flowing over gentle slopes, develop sinuous or meandering courses. It is common to find meandering courses over floodplains and delta plains where stream gradients are very gentle. But very deep and wide meanders can also be found cut in hard rocks. Such meanders are called incised or entrenched meanders (Figure 7.2). Meander loops develop over original gentle surfaces in the initial stages of development of streams and the same loops get entrenched into the rocks normally due to erosion or slow, continued uplift of the land over which they start. They widen and deepen over time and can be found as deep gorges and canyons in hard rock areas. They give an indication on the status of original land surfaces over which streams have developed.

River Terraces
River terraces are surfaces marking old valley floor or floodplain levels. They may be bedrock surfaces without any alluvial cover or alluvial terraces consisting of stream deposits. River terraces are basically products of erosion as they result due to vertical erosion by the stream into its own depositional floodplain. There can be a number of such terraces at different heights indicating former river bed levels. The river terraces may occur at the same elevation on either side of the rivers in which case they are called paired terraces.

When a terrace is present only on one side of the stream and with none on the other side or one at quite a different elevation on the other side, the terraces are called non-paired terraces. Unpaired terraces are typical in areas of slow uplift of land or where the water column changes are not uniform along both the banks. The terraces may result due to (i) receding water after a peak flow; (ii) change in hydrological regime due to climatic changes; (iii) tectonic uplift of land; (iv) sea level changes in case of rivers closer to the sea.
4.4 Depositional Landforms of River

Alluvial Fans
Alluvial fans (Figure 7.4) are formed when streams flowing from higher levels break into foot slope plains of low gradient. Normally very coarse load is carried by streams flowing over mountain slopes. This load becomes too heavy for the streams to be carried over gentler gradients and gets dumped and spread as a broad low to high cone shaped deposit called alluvial fan. Usually, the streams which flow over fans are not confined to their original channels for long and shift their position across the fan forming many channels called distributaries. Alluvial fans in humid areas show normally low cones with gentle slope from head to toe and they appear as high cones with steep slope in arid and semi-arid climates.

Deltas
Deltas are like alluvial fans but develop at a different location. The load carried by the rivers is dumped and spread into the sea. If this load is not carried away far into the sea or distributed along the coast, it spreads and accumulates as a low cone. Unlike in alluvial fans, the deposits making up deltas are very well sorted with clear stratification. The coarsest materials settle out first and the finer fractions like silts and clays are carried out into the sea. As the delta grows, the river distributaries continue to increase in length and delta continues to build up into the sea. Deposition develops a floodplain just as erosion makes valleys.

Floodplains:
Floodplain is a major landform of river deposition. Large sized materials are deposited first when stream channel breaks into a gentle slope. Thus, normally, fine sized materials like sand, silt and clay are carried by relatively slow-moving waters in gentler channels usually found in the plains and deposited over the bed and when the waters spill over the banks during flooding above the bed. A river bed made of river deposits is the active floodplain. The floodplain above the bank is inactive floodplain. Inactive floodplain above the banks basically contain two types of deposits — flood deposits and channel deposits. In plains, channels shift laterally and change their courses occasionally leaving cut-off courses which get filled up gradually. Such areas over flood plains built up by abandoned or cut-off channels contain coarse deposits. The flood deposits of spilled waters carry relatively finer materials like silt and clay. The flood plains in a delta are called delta plains.

Natural Levees
Natural levees and point bars are some of the important landforms found associated with floodplains. Natural levees are found along the banks of large rivers. They are low, linear and parallel ridges of coarse deposits along the banks of rivers, quite often cut into individual mounds. During flooding as the water spills over the bank, the velocity of the water comes down and large sized and high specific gravity materials get dumped in the immediate vicinity of the bank as ridges. They are high nearer the banks and slope gently away from the river.
The levee deposits are coarser than the deposits spread by flood waters away from the river. When rivers shift laterally, a series of natural levees can form.

**Point bar**

Point bars are also known as meander bars. They are found on the convex side of meanders of large rivers and are sediments deposited in a linear fashion by flowing waters along the bank. They are almost uniform in profile and in width and contain mixed sizes of sediments. If there more than one ridge, narrow and elongated depressions are found in between the point bars. Rivers build a series of them depending upon the water flow and supply of sediment. As the rivers build the point bars on the convex side, the bank on the concave side will erode actively. Point bars are also known as meander bars. They are found on the convex side of meanders of large rivers and are sediments deposited in a linear fashion by flowing waters along the bank. They are almost uniform in profile and in width and contain mixed sizes of sediments. If there more than one ridge, narrow and elongated depressions are found in between the point bars. Rivers build a series of them depending upon the water flow and supply of sediment. As the rivers build the point bars on the convex side, the bank on the concave side will erode actively.

**Meanders**

In large flood and delta plains, rivers rarely flow in straight courses. Loop-like channel patterns called meanders develop over flood and delta plains. Meander is not a landform but is only a type of channel pattern. This is because of (i) propensity of water flowing over very gentle gradients to work laterally on the banks; (ii) unconsolidated nature of alluvial deposits making up the banks with many irregularities which can be used by water exerting pressure laterally; (iii) Coriolis force acting on the fluid water deflecting it like it deflects the wind. When the gradient of the channel becomes extremely low, water flows leisurely and starts working laterally. Slight irregularities along the banks slowly get transformed into a small curvature in the banks; the curvature deepens due to deposition on the inside of the curve and erosion along the bank on the outside. If there is no deposition and no erosion or undercutting, the tendency to meander is reduced. Normally, in meanders of large
rivers, there is active deposition along the convex bank and undercutting along the concave bank. The concave bank is known as cut-off bank which shows up as a steep scarp and the convex bank presents a long, gentle profile and is known as slip-off bank. As meanders grow into deep loops, the same may get cut-off due to erosion at the inflection points and are left as ox-bow lakes.

**Braided Channels**

When rivers carry coarse material, there can be selective deposition of coarser materials causing formation of a central bar which diverts the flow towards the banks; and this flow increases lateral erosion on the banks. As the valley widens, the water column is reduced and more and more materials get deposited as islands and lateral bars developing a number of separate channels of water flow. Deposition and lateral erosion of banks are essential for the formation of braided pattern. Or, alternatively, when discharge is less and load is more in the valley, channel bars and islands of sand, gravel and pebbles develop on the floor of the channel and the water flow is divided into multiple threads. These thread-like streams of water rejoin and subdivide repeatedly to give a typical braided pattern.

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