

Introduction to rocks and minerals:

A mineral is a naturally occurring inorganic solid having a regular and orderly internal atomic arrangement and possessing a definite chemical composition. Any substance that does not fulfill even a single criterion among these cannot be called as a mineral. A mineral may be composed of a single chemical element (Au--Gold) or a specific combination of different chemical elements (SiO_2 --Quartz). The geologist who studies minerals is known as mineral mineralogist. Till now mineralogist have discovered more than 3000 mineral and around 50 new minerals are discovered every year. Some examples of minerals are: Quartz, feldspars, olivine, hematite, galena, pyrite etc.

A rock may be defined as an aggregate of minerals. However, a rock necessarily need to be composed of any minerals, it can made up of only one mineral in which case the rock is called monomineralic rock or otherwise a polymineralic rock. For example Granite is an igneous rock which contains granular minerals of quartz, microcline and/ or orthoclase, Na-plagioclase feldspar and muscovite. This rock is a polymineralic rock. Similarly, Dunite is another rock that is almost entirely composed of mineral olivine and hence a monomineralic rock.

Rocks as natural mineral aggregates:

The rigid outermost layer of the earth comprising of the uppermost part of the mantle and the crust is called lithosphere. The word litho literally means rock, so we can say that the earth's outermost shell is rockshpere, i.e. made of rocks. A rock is made up of minerals which in turn are made of atoms or ions. These atoms or ions in a mineral are arranged regularly and orderly in a repetitive pattern and are formed inorganically and naturally with a definite ionic ratio. So a rock can be defined as a naturally occurring aggregate of minerals and the aggregation of minerals in a rock is in such a way that individual minerals retain their identity. It may be noted here that there are few non-mineralic rocks which include volcanic glass, obsidian, pumice and coal.

Types of Rocks:

Igneous rocks:

The term igneous has been derived the Latin word ignis which means fire. The name is given to the rocks that have formed from extremely hot molten material called magma. The magma originates deep in the earth's mantle where temperature is high enough to melt the rocks. The molten rock material in the mantle is under very high pressure and with a very little change in the physical properties the magma starts to ascent because of its buoyancy. During it upward movement the magma loses its heat and it starts to solidify. On solidification it gives rise hard crystalline either under the surface or over it. The rocks that are formed from the magma under the surface of the earth are called intrusive or plutonic (hyperbasal rocks if the rocks are formed in the intermediate vicinity under the earth's surface) rocks and the process of formation is called igneous intrusion. If the magma is very mobile it reaches to the surface of earth and then it is called lava and the rocks formed from lava are called extrusive or volcanic rocks and the process is of formation is called volcanic eruption. The cone shaped feature formed by a volcanic eruption on the surface of earth is called a volcano

Sedimentary rocks:

Sedimentary rocks are those rocks that are formed from the accumulation, compaction and consolidation of sediments derived from preexisting rocks by the process of weathering and erosion. Sedimentary rocks are formed by complex mechanical, chemical and even sometime biological processes. Sediments are particles

or fragments derived from preexisting rocks (igneous, sedimentary or metamorphic) by physical disintegration or chemical action and are left insitu. This process is known as weathering. If the weathered material is transported from the site of weathering by the agents of transportation like wind, water or glaciers, then the process is called erosion. The eroded material is then deposited at some suitable place where it is accumulated, compressed under load and consolidated. Then the individual sediments are cemented together to form sedimentary rocks. Sedimentary rocks can be classified into three broad types on the basis of the sediments involved in the formation of rocks as: clastic or detrital sedimentary rocks, Chemical sedimentary rocks and organic sedimentary rocks.

Clastic or detrital sedimentary rocks:

Clastic rocks are formed by physical disintegration of the preexisting rocks and the transportation and deposition of the disintegrated material to a sedimentary basin where the deposited material undergo compaction and consolidation and the sediments are then welded and cemented together to form a sedimentary rock. These rocks are also called mechanically formed rocks.

Chemical sedimentary rocks:

Physical disintegration and chemical decomposition of pre-existing rocks generate chemical components. These chemical components are dissolved in surface and groundwater. When the water becomes saturated with the chemical components, this dissolved material precipitated to form a chemically formed sedimentary rock. These rocks are formed in playas, lakes and ocean, where precipitation takes place largely and purely by inorganic processes. The principal purely chemical sedimentary rock type is evaporate (halite).

Biogenic, biochemical, or organic sedimentary rocks:

More than 70 percent of the earth is covered by oceans and seas. These extensive water bodies are home of a variety of plants and animals. Many animals living in these water bodies have endo or exoskeleton primarily made of carbonate. When these organisms die their soft parts are decomposed and the hard parts accumulate. When huge accumulations of these carbonates are stacked together the underlying carbonates are compacted and consolidated under high pressure exerted by overlying material. With the passage of time these carbonate are welded together and cemented and lithified to form carbonate sedimentary rocks. A typical example of such type of rocks is Limestone.

Metamorphic rocks:

The term metamorphism comes from (meta morph) meaning change of form. In petrology, metamorphism refers to changes in a rock's mineralogy, texture, and/or composition that occur necessarily in the solid state under conditions between those of diagenesis and large-scale melting. The rocks that are formed in response to the metamorphism are called metamorphic rock. The primary agents of metamorphism are temperature, pressure and hydrothermal solutions. There are two main types of metamorphic rocks on the basis of presence or absence of preferred orientation of platy and flaky minerals. The two sub-divisions of metamorphic rocks are: foliated rocks and non-foliated rocks.

Foliated rocks:

Foliated metamorphic rocks are those rocks in which platy and flaky minerals have a preferred orientation i.e. the longer axis of the minerals is oriented in a particular direction. For example slate, phyllite, and schist are foliated rocks.

Non-foliated rocks:

Non-foliated rocks are those metamorphic rocks which consist predominantly of equidimensional grains and do not show any preferred orientation of minerals. For example quartzite, marble and granulite are non-foliated metamorphic rocks.

Rock forming and economic minerals:

Minerals constitute the fundamental material of the earth. Mineral science is commonly known as mineralogy is the study of naturally occurring solid substances called minerals. A mineral is a naturally occurring solid with a highly ordered atomic arrangement and a definite chemical composition and is formed by inorganic processes. A highly ordered atomic arrangement means an internal structural framework of atoms or ions, arranged in a regular geometric pattern. Several natural solids such as volcanic glass are amorphous and are not classified as minerals rather they are classified as mineraloids. A definite chemical composition implies that it can be expressed by a specific chemical formula. For example quartz is expressed as SiO_2 . Some minerals do not have a well-defined chemical composition. For example dolomite, $\text{CaMg}(\text{CO}_3)_2$ is not always a pure Ca-Mg carbonate. Such chemical formula is referred to as an end member composition. The earth and the planets are made up of rocks which themselves consists of an aggregate of one or more minerals commonly referred to as rock forming minerals. Rock forming minerals are widely distributed throughout the crust and the lithosphere. However there is another group of minerals which has a somewhat rare distribution in the lithosphere and this group of mineral is called ore forming minerals. The ore forming minerals are those which are of value to man. They are further classified as metallic (matelliferous) and non- metallic (utilized in the industry) minerals. The matelliferous and industrial minerals are together called economic minerals.

Physical and chemical properties of the earth:

The earth's interior is not directly accessible and hence cannot be sampled and analyzed to know its physical and chemical characteristics. However, there are certain indirect methods by which we can estimate the physical and chemical properties of the earth's interior. These indirect methods include ophiolites and greenstone belts, volcanic eruptions, xenoliths, boreholes and seismic data. The first five methods however, give us information only about the crust and the upper mantle. The seismic waves travel through the whole interior of the earth and therefore are readily used to estimate the physical and chemical characteristic of the earth. By analyzing seismic refraction and reflection data from all over the world, geophysicists have identified three concentric parts of the earth: the crust, mantle, and the core.

Physical properties and chemical composition of the earth and earth's crust:

The Crust:

The crust is a relatively thin, rocky outer skin, of the earth and is of two types—continental crust and oceanic crust.

Upper Continental Crust:

This is the outer most of the earth and forms the surface of the earth. The average thickness of the upper continental crust is 17 kilometers. It is primarily composed of crystalline rocks with low-density buoyant minerals that are largely dominated by silicates (Quartz; SiO_2) and feldspars (metal-poor silicates). This composition corresponds to a rock type between granodiorite and diorite, and is characterized by a relatively high concentration of the heat-producing elements.

Middle and Lower Continental Crust:

The average lower crust begins at 23 km depth and is 17 km thick. However, the depth and thickness of both middle and lower crust vary considerably from place to place. In tectonically active rifts and rifted margins, the middle and lower crust generally are thin. The lower crust in these settings can range from negligible to more than 10 km thick. The lower crust is compositionally more complex than suggested by simple geophysical models. Studies of deep crustal xenoliths and crustal contaminated magmas indicate that there are significant regional variations in its composition, age, and thermal history. Deep seismic reflection investigations suggest that the

composition of the middle and lower crust more mafic and the rocks are dense. The upper and lower crust is separated by Conrad seismic discontinuity. The average overall density of the continental crust is 2.7 g/cm^3

Oceanic Crust:

On an average the oceanic crust is 7 kilometers thick. This 7 kilometer thick crust is further divided into three sub layers on the basis of physical and chemical properties of rocks found here.

Oceanic layer 1:

The average thickness of this layer is 0.4 kilometers with least thickness at ridges and greatest thickness near oceanic trenches. The layer may sometimes be absent near the ridge system. The layer consists of unconsolidated deposits including terrigenous sediments carried into the deep oceans by turbidity currents, and pelagic deposits such as brown zeolite clays, calcareous and silicic oozes, and manganese nodules.

Oceanic layer 2:

This layer varies in its thickness from 1.0 to 2.5 kilometers. Its seismic velocity is similarly variable in the range 3.4–6.2 km/sec. This layer has been directly sampled near sediment-free ridge crests and it has been found that the layer is composed of olivine tholeiites containing calcic plagioclase.

Oceanic layer 3:

The average thickness of this layer is 5 kilometers and is formed by plutonic rocks. It is composed of gabbroic rocks in its upper part and serpentinized ultramafic rocks called peridotite in its lower parts. The overall average density of the oceanic crust is 3.0 g/cm^3

The Mohorovicic discontinuity:

The Mohorovicic discontinuity, or Moho, is the first major seismic boundary of the earth's interior which separates the crust from the underlying mantle. It is named after Yugoslavian seismologist Andrija Mohorovicic, who in 1909 presented the first evidence for the layered internal structure of the earth. The Moho occurs at a depth that ranges from 5 to 50 kilometers from the surface. This discontinuity occurs everywhere under the crust.

The Mantle:

The Upper Mantle:

Down to a depth of 660 kilometers extends the upper mantle, the upper boundary of which is Moho discontinuity. The upper mantle can be divided into three sub layers. The top portion of the upper mantle is part of the stronger lithosphere, and beneath that is the weaker asthenosphere. The bottom part of the upper mantle is called the transition zone. Entire crust plus the uppermost mantle and forms Earth's relatively cool, rigid outer shell called lithosphere. The average thickness of the lithosphere is 100 kilometers. Beneath this stiff layer to a depth of about 410 kilometers lies a soft, comparatively weak layer known as the asthenosphere ("weak sphere"). The top portion of the asthenosphere has a temperature/pressure regime that results in a small amount of melting. Within this very weak zone, the lithosphere is mechanically detached from the layer below. It is important to emphasize that the strength of various Earth materials is a function of both their composition and of the temperature and pressure of their environment. In the uppermost asthenosphere, the rocks are close enough to their melting temperature that they are deformed very easily. From about 410 kilometers to about 660 kilometers in depth is the part of the upper mantle called the transition zone. At the top of the transition zone there is sudden increase in density from about 3.5 to 3.7 g/cm^3 . This change occurs as the olivine in the peridotite respond to the increase in pressure by transforming to the spinel structure with closely packed atomic structures.

The Lower Mantle:

The layer from the depth of 660 kilometers to the top of the core, at a depth of about 2891 kilometers is the lower mantle. This zone represents almost 50% of the mass of the entire Earth. There is generally smooth increase in the seismic wave velocity in this region suggesting homogeneity in mineralogy with a perovskite structure. In the bottom 200 to 300 hundred kilometers of the mantle is a highly variable and heterogeneous layer called the D"layer (pronounced "dee double-prime"). In this layer the seismic wave velocity decreases which is probably due an increased temperature gradient above the mantle-core boundary.

The Core:

At a depth of 2891 km occurs the core of the earth, and occupies the center of the Earth. The core is composed of an iron–nickel alloy with minor amounts of oxygen, silicon, and sulfur. The boundary between the mantle and the core is called Gutenberg discontinuity. Seismological studies have shown that the core has an outer shell that exists between 2891 to 5100 km, with an average density of 10 g/cm³. The inner core exists between a depth of 5100 to 6378 km is in solid form with an average density estimated to be 13 g/cm³.

Rocks and the history of the earth:

From the time of its origin about 4.5 billion years to the present day, the Earth has been continuously changing. Continents that we see today were once together and they have ponderously drifted across the face of the globe and slowly collided with other landmasses to form lofty mountain ranges. Massive glaciers have buried vast tracts of forest. Earth has witnessed recurrent earthquakes, rampant volcanism, catastrophic impacts of meteorites and asteroids, and major changes in the chemistry of the ocean and atmosphere. Along with these physical changes, life on Earth has also undergone change; sometimes slow, but occasionally swift and deadly. All these changes have been documented in the rocks of the earth in a chronological order just as the pages in a history book. A careful and scientific examination of these rocks reveals the entire history of the earth. However, there are few geological tools which yield more authentic data than others. The chief geological tools that give clue about history of the earth are:

Fossils:

Fossils are the remains of plants and animals that lived on the earth in the geological past and were buried in sediments that were later lithified into rock. These fossils are preserved in many forms and modes. All of these preservations permit us to discern the history of life and the history of the earth. Since the life originated in the Precambrian era the sedimentary rocks ranging in age from Precambrian to recent contain one fossil or the other in different parts of the world. These rocks are formed from the deposition and lithification of the sediments in such a way that the oldest undisturbed rocks and hence the fossils lie at the bottom and the youngest at the top (order of superposition). These rocks from bottom to top continuously contain remains of evolved life forms (law of floral and faunal succession). The order of superposition and the law of faunal and floral succession when considered together help us to understand which rocks were deposited in what environmental conditions; both physical and chemical and also give insights to complexity of life forms at the time of formation of the rock. Further, when sedimentary sequences of two different region containing either similar or dissimilar fossils are correlated help us to determine their relative ages.

Mineralogy and texture:

Many minerals form within a narrow range of physical conditions. Thus, their presence (or absence) can be used to understand what pressures and temperatures existed during the formation of an igneous or a metamorphic rock. For example quartz has certain polymorphic forms which are stable within very narrow range of pressures and temperatures. Some minerals develop primarily in ocean water. Thus, their

presence is evidence of former seas. Some minerals form only under highly arid conditions. Their presence is evidence of former arid tropical belts. Magnetic minerals record the direction of Earth's magnetic field at the time the minerals or the rock was formed, thus providing clues to drifting of continents, widening of oceans, and movement of our planet's magnetic poles. Similarly from sedimentary rocks we can infer source of the material and prevailing environmental conditions at the time of formation of the rocks by looking at its mineralogy. The mineralogy of the metamorphic rocks gives significant clues about the type of metamorphism and the intensity of the metamorphic agents.

The grain size of igneous rocks tells us how they cooled, and therefore much about the environment that existed when they formed can be reconstructed. Magmas deep within Earth lose heat very slowly; therefore the individual mineral grains in such rocks are large enough to be seen with an unaided eye. Contrary to this the mineral grains in the volcanic rocks are very fine and even glassy suggesting rapid cooling and hence the environment of solidification.

The texture of the sedimentary rocks size, shape and sorting of grains tells us about the turbulence and velocity of currents and the extent of transportation. Texture provides clues to a rock's history. For example, in carbonate rocks, extremely fine-grained textures indicate deposition in quiet water, because such tiny particles of calcium carbonate are unlikely to be deposited in turbulent water. The presence of whole, unbroken fossil shells confirms the quiet water interpretation. On the other hand, limestone that contains a mixture of worn and broken shell fragments is likely to be the product of reworking by wave action. From studies of the minerals in metamorphic rocks and the texture of the rocks, it is possible to reconstruct the conditions under which the rocks were altered. For example hornfels are formed due to contact metamorphism of pelitic rocks.

Structures:

Few in sedimentary rocks form during or shortly after deposition, but before lithification. Because these structures result from specific depositional processes, they are extremely useful in reconstructing ancient environments. The structures are mud cracks, cross-bedding, graded bedding, and ripple marks. Mud cracks indicate drying after deposition. These conditions are common on valley flats, along the muddy margins of lakes, and in tidal zones. Mud cracks develop by shrinkage of mud or clay on drying and are formed on the land surface. Thus, when mud cracks are found in a rock, geologists know that the mud was exposed to air. Cross-bedding (cross-stratification) is an arrangement of beds or laminations in which one set of layers is inclined relative to the others. Cross-bedding can form whenever wind or water transports and deposits clastic particles. Wind may heap sand into dunes, or water currents may produce similar features. Grains moved by the currents tumble down the steep downwind (or downstream) side to form layers that are inclined relative to the horizontal layers beneath them. From cross-bedding, we infer a depositional environment dominated by wind or water currents which were multi-directional.

The structures of igneous rocks similarly provide ample evidences of the cooling history of the rocks and the chemical and physical characteristics of the magma. For example, ropy and blocky lava structures suggest that magma was very mobile and of mafic type. Similarly, pillow structure in basalts is formed under marine conditions.

The metamorphic structures like foliation and lineation are the proof that the rocks have undergone intense compression, hence suggesting the rocks have been formed under compressional regime like shear zone, fold belts, and convergent margins etc. though the rocks may not be in any such environment at present.

Paleogeography and Paleoclimate:

Paleogeography deals with Earth's geography of the past. The continents and oceans are mobile and have not remained fixed during the geological history of the planet

because of plate movements. Vertical tectonics has also played a part in the distribution of continents and oceans in the past. For example in the late Paleozoic times all the land masses that are at present distributed throughout the globe were united together into one landmass known as Pangea as was demonstrated by Wegner. His theory was supported by geological evidences like similar rocks, glacial striations and mountain ranges on the east coast of South America and the west coast of Africa. Another evidence for changing positions of the continents and the oceans are the surfaces of nondeposition or the unconformities. Further, by using the sedimentary structures like ripple marks, current bedding, and sole marks etc. we can deduce the direction of paleocurrents which in turn reveals paleogeography. Paleogeography can also be inferred from the sediment core analysis ocean bottom by knowing past marine transgressions and regressions.

Paleoclimate is the study of past climate of the earth and can be inferred by using various geological techniques like the stable oxygen isotope data preserved in the marine sediments and continental ice sheets and glaciers. Pollen analysis is particularly useful in paleoclimatology. Pollen grains, produced by the male reproductive bodies of seed plants, have a resistant waxy coating that ensures many will be preserved in the fossil record. Most seed plants disperse pollen by wind, so it settles in streams, lakes, swamps, bogs, and in near shore marine environments. Once paleontologists recover pollen from sediments, they identify the type of plant it came from, determine the floral composition of the area, and make climatic inferences. Dendroclimatology and lichenometry are other geological techniques which can be used to understand Paleoclimate.

Surface relief of the earth:

Most of the landscape features of the earth's surface that we see today developed during the Cenozoic Era which began 65 million years ago. The major relief features of the earth's surface are the continents and ocean basins.

Relief features of continents:

The continents occupy approximately 30% of the earth's total area. The main **continental relief forms are:**

Mountains: A mountain can be defined as an area of land that rises abruptly from the surrounding region. A mountain range is a succession of many closely spaced mountains covering a particular region of the Earth. Mountain belts consist of several mountain ranges that run roughly parallel to each other. The North American Cordillera, the Himalayas, the Alps, and the Appalachians are all examples of mountain belts that are composed of numerous mountain ranges.

Valleys: valley is a long "depression" (or low part) in the land, between two higher parts which might be hills or mountains. Valleys often start as a downward fold between two upward folds in the surface of the Earth. A valley is made deeper by a stream of water or a river as it flows from the high land to the lower land, and into a lake or sea. Some valleys are made by glaciers which are slow-moving rivers of ice. When a valley is made deeper or wider by water or ice, this is called erosion. Wind can also make valleys larger by erosion.

Plains: plain, large area of level or nearly level land. Elevated plains are called plateaus, or tablelands, and very low, wet plains are called swamps. Plains have different names in different climates and countries. They include the tundra, steppes, prairies, pampas, savannas, and llanos, floodplains of rivers, coastal plains, loess plains, and arid plains. The erosive action of water, glaciation, the draining of a lake, deposition of sediment, and the uplift of a continental shelf are some of the causes of the formation of plains.

Plateaus:

Plateau is an extensive area of flat upland usually bounded by an escarpment (i.e., steep slope) on all sides but sometimes enclosed by mountains. The essential criteria

for plateaus are low relative relief and some altitude. Although plateaus stand at higher elevation than surrounding terrain, they differ from mountain ranges in that they are remarkably flat. Some plateaus, like the Altiplano in southern Peru and western Bolivia, are integral parts of mountain belts. Others, such as the Colorado Plateau (across which the Colorado River has cut the Grand Canyon), were produced by processes very different from those that built neighboring mountain ranges. Some plateaus; for example, the Deccan plateau of central India occur far from mountain ranges. The differences among plateaus can be ascribed to the different geologic processes that have created them.

Relief features of oceans floor:

The oceans cover approximately 70% of the earth's total area. The main relief features of ocean bottom floor are:

Continental Shelf:

Oceans are full of water. Some of it spreads on to the neighboring land. The portions of the land, which are submerged under sea water, constitute continental shelf. The continental shelf is shallow and its depth is not more than 200 meters. Its slope from the land to the sea is about 2 meters per km. The breadth of the continental shelf is not the same everywhere. The maximum breadth is almost equal to 1,100 km. found between Northern Norway and Novaya Zemlya along Berints Sea. An extensive shelf along the Arctic Coast Ranges 480 km to 1280 km wide and 183 m deep. The deepest shelves surround the Antarctic continent. The continental shelves cover about 7.6% of the total area of the sea.

Continental slope:

At the outer edge of the continental shelf, the slope suddenly steepens. This is found to be 35 to 61 meters per km. The value of the slope is more adjacent to the fold mountains than that near the coastal plains. One end of the slope connects it with continental shelf while the other one merges into the ocean floors. The area occupied by continental slope is 8.5% of the total ocean area.

Continental Rise:

The continental slope gradually loses its steepness with depth. When the slope reaches a level of between 0.5° and 1° , it is referred to as the continental rise. With increasing depth the rise becomes virtually flat and merges with the abyssal plain.

Submarine Canyons:

These are steep valleys, forming deep gorges on the ocean floor. They are mainly restricted to the continental shelf, slope and rise.

Abyssal Plains:

Beyond the continental rise, at depths from 3,000 m to 6,000 m, lie the deep sea plains, called abyssal plains or abyssal floors. Covering nearly 40% of the ocean floor, the abyssal plains are present in all major oceans and several seas of the world. They are uniquely flat with a gradient of less than 10,000. The large supply of terrigenous and shallow water sediments buries the irregular topography to form a generally flat relief.

Submarine Ridges:

Submarine ridges are mountain ranges, a few hundred kilometers wide and hundreds and often thousands of kilometers in length on the floors of oceans. Running for a total length of 75,000 km, these ridges form the largest mountain systems on earth.

These ridges are either broad, like a plateau, gently sloping or in the form of steep-sided narrow mountains. These oceanic ridge systems are of tectonic origin and provide evidence in support of the theory of Plate Tectonics.

Abyssal Hills:

These are elevated features of volcanic origin. A submarine mountain or peak rising more than 1,000 meters above the ocean floor is known as a seamount. The flat topped mountains are known as guyots.

Submarine Trenches or Deep:

These are the deepest parts of the oceans with their bottoms far below the average level of the ocean floors. A trench is a long, narrow and steep-sided depression on the ocean bottom, which is usually 5,500 meters in depth. The trenches lie along the fringes of the deep-sea plain and run parallel to the bordering fold mountains or the island chains. They are believed to have resulted from down faulting or down folding of the earth's crust and are, therefore, of tectonic origin. The trenches are very common in the Pacific Ocean and form an almost continuous ring along the western and eastern margins of the Pacific. The Mariana Trench off the Guam Islands in the Pacific Ocean is the deepest trench with a depth of more than 11 kilometers.

Exogenous and endogenous processes:

The surface of the earth is shaped by many different geological processes. The forces that cause these processes originate either above the surface of the earth or below it i.e. inside the earth. Processes that are caused by forces from within the Earth are called endogenous processes and the processes that are the result of the forces which originate above the earth are called exogenous.

Endogenous processes:

These are also known as hypogene or processes. Endogenous processes cause phenomena, like earth-quakes, emergence and development of continents, ocean troughs and mountain ridges, generation of volcanic activity, metamorphism of pre-existing rocks, deformation and movement of the earth's crust both vertically and laterally etc. The geomorphic features produced by these processes provide the setting for exogenous processes to act upon. All features which owe their origin to an endogenous process are invariably modified by exogenous processes. The endogenous processes are mostly caused by the thermal energy of the mantle and the crust. This thermal energy is derived from the decay and disintegration of the radioactive elements and from gravitational differentiation in the mantle. Some of the important endogenous processes are:

Earthquakes:

Sudden shaking of the earth due to release of trapped energy in the earth's lithosphere is called an earthquake. Earthquakes range from a faint tremors to a wild motions capable of bringing down buildings and causing fissures to open up in the ground. The earthquakes are mostly produced due to underground dislocation of rocks.

Tectonic movements:

Tectonic movements of lithosphere are of various forms and are characterized by great complexity. In the course of geological history of the earth, the rocks have been crumpled into folds, thrust over one another, broken up etc. giving rise to mountains, ridges, ocean trough and other landforms. The tectonic process of elevating or building up portions of the earth's surface is called diastrophism, which prevents the exogenous process from ultimately reducing the earth's land areas to sea-level. It is of two types viz. Orogeny and Epeirogeny. Orogeny refers to process of mountain building activities with deformation of the crust and lithosphere and Epeirogeny refers to regional uplift with marked deformation.

Volcanism:

It is the phenomenon in which molten rock material is transferred from the earth's interior and erupted onto its surface. It is one of the important manifestations of the dynamic nature of the earth. The process of outpouring of magmatic material on to the surface of the earth, thus forming volcanic rocks is called volcanism. Sometimes the magma on its way upward does not reach the surface and cools at various depths giving rise to magmatic rocks of irregular form, which are called intrusives or plutons. The phenomenon is known as Intrusive magmatism. Even though the intrusions are not directly responsible for topographic features their existence in the upper crust of

the earth may affect to a great extent the topographic features of the area formed by exogenous processes.

Metamorphism:

Metamorphism involves the transformation of preexisting rocks into new types by the action of pressure, temperature, pressure and chemically active fluids. The main feature of the metamorphic processes is that the changes take place in solid state. The metamorphic agents like temperature, pressure and chemically active fluids are a result of the dynamic forces that originate within the earth's interior.

Exogenous processes:

These are the processes of external origin or, in other words, the processes that derive their energy from sources external in relation to the earth viz. energy from the sun, the force of gravity, and the activity of organisms etc. Thus the exogenous processes are closely linked with the role of various external agents such as blowing wind, surface and groundwater, waves and currents in water bodies, (seas and oceans), glaciers etc. Since these processes are restricted to the surface of the earth, exogenous processes are also called epigene processes. These processes play important role in the evolution and development of the landscape of the earth's surface. The most important exogenous processes are:

Weathering and Erosion:

Weathering is the process of decomposition and disintegration of rocks and minerals at the Earth's surface under the influence of atmospheric agents like air, water, wind and temperature. Weathering itself involves little or no movement of the decomposed rocks and minerals. This material accumulates where it forms and overlies unweathered bedrock. Weathering occurs by both mechanical and chemical processes. Mechanical weathering reduces solid rock to rubble but does not alter the chemical composition of rocks and minerals. In contrast, chemical weathering occurs when air and water chemically react with rock to alter its composition and mineral content. These chemical changes are analogous to rusting in that the final products differ both physically and chemically from the parent material.

Erosion is the removal of weathered rocks and minerals by moving water, wind, glaciers, and gravity. After a rock fragment has been eroded from its place of origin, it may be transported large distances and when the transporting agent loses energy, transport stops and sediments are deposited.

Various Geospheres:

Lithosphere:

The uppermost part of the mantle and the crust together constitute the relatively rigid shell of the earth called lithosphere. Lithosphere extends from 80 to 100 kilometers down from the surface of the earth. The thickness of the lithosphere is highest nearly 120 kilometers under young fold mountain regions and lowest under mid-oceanic ridge systems. The average composition by weight of chemical elements in the lithosphere is oxygen 47 per cent, silicon 28 per cent, aluminium 8.1 per cent, iron 5.0 per cent, calcium 3.6 per cent, sodium 2.8 per cent, potassium 2.6 per cent, magnesium 2.1 per cent, and the elements 0.8 per cent. These elements combine to form minerals. The chief minerals in the lithosphere are feldspars (aluminium silicates with potassium, sodium, or calcium), quartz (a form of silicon dioxide), clay minerals (complex aluminium silicates), iron minerals such as limonite and hematite, and ferromagnesian minerals (complex iron, magnesium, and calcium silicates). Lithosphere is not a continuous layer of rocks spread over the globe but is broken into smaller fragments called lithospheric plates or tectonic plates. There are seven lithospheric plates each with an area over 100 million square kilometers and more than 20 small plates whose area range from 1 – 10 square kilometers. Lithosphere is

an open system that continuously exchanges matter and energy with its surroundings.

Atmosphere:

By virtue of its gravity the earth holds a thick cover of gasses around it. This gaseous cover consisting of various gasses, water vapor, various salts and dust particles which surrounds the earth is called atmosphere. The atmosphere extends to more than 700 kilometers above Earth's surface. Its density decreases rapidly with altitude; in fact, 97% of the air is concentrated in the first 25 kilometers (16 mi) or so. Because air has mass, the atmosphere exerts pressure on Earth's surface. At sea level, this pressure is about 1034 grams per square centimeter (14.7 lb/sq in.), but the higher the elevation, the lower is the atmospheric pressure.

Composition of the Atmosphere:

The atmosphere is composed of numerous gases (Table 2.1). Most of these gases remain in the same proportions regardless of the density of the atmosphere. A bit more than 78% of the atmosphere's volume is made up of nitrogen, and nearly 21% consists of oxygen. Argon comprises most of the remaining 1%.The percentage of carbon dioxide in the atmosphere has risen through time, but is a little less than 0.04% by volume. There are traces of other gases as well: ozone, hydrogen, neon, xenon, helium, methane, nitrous oxide, krypton, and others.

Component	Volume (in %)
Nitrogen (N ₂)	78.084
Oxygen (O ₂)	20.948
Argon (Ar)	0.934
Carbon Dioxide (CO ₂)	0.033
Others (Ne, H, CH ₄ , Kr, H ₂ , Xe, etc.)	0.002

Table 2.1 Showing composition of the atmosphere at present

Nitrogen gas (N₂) makes up the largest proportion of air. It is a very important element supporting plant growth. In addition, some of the other gases in the atmosphere are vital to the development and maintenance of life on Earth. One of the most important of the atmospheric gases is of course oxygen (O₂), which humans and all other animals use to breathe and oxidize (burn) the food that they eat. The third most abundant gas in our atmosphere is Argon (Ar). It is not a chemically active gas and therefore neither helps nor hinders life on Earth. Carbon dioxide (CO₂), the fourth most abundant gas, is involved in the system known as the carbon cycle. Plants, through a process known as photosynthesis, use carbon dioxide and water to produce carbohydrates (sugars and starches), in which amounts of energy, derived originally from the sun, are stored and used by vegetation. Oxygen is given off as a by-product. Animals then use the oxygen to oxidize the carbohydrates, releasing the stored energy. A by-product of this process in animals is the release of carbon dioxide, which completes the cycle when it is in turn used by plants in photosynthesis.

Water vapor is always mixed in some proportion with the dry air of the lower part of the atmosphere; it is the most variable of the atmospheric gases and can range from

0.02% by volume in a cold, dry climate to more than 4% in the humid tropics. Water vapor also absorbs heat in the lower atmosphere and so prevents its rapid escape from Earth. Thus, like carbon dioxide, water vapor plays a large role in the insulating action of the atmosphere. In addition to gaseous water vapor, liquid water also exists in the atmosphere as rain and as fine droplets in clouds, mist, and fog. Solid water is found in the atmosphere in the form of ice crystals, snow, sleet, and hail. Particulates are solids suspended in the atmosphere. These can be pollutants from transportation and industry, but the majority is natural particles that have always existed in our atmosphere. Particles such as dust, smoke, pollen and spores, volcanic ash, bacteria, and salts from ocean spray can all play an important role in absorption of energy and in the formation of raindrops.

Structure of the atmosphere:

The atmosphere is the envelope of air surrounding the Earth. It consists of a physical mixture of gases and particulate matter. Common people are primarily concerned with the lowest level of the atmosphere, however, when we fly in aircraft or climb a mountain; we come across the other parts of the atmosphere which are at higher altitudes than our normal living place. At these higher altitudes we feel cooler air temperature and rarity in the atmospheric gasses as we feel difficulty in breathing. This suggests that the earth's atmosphere is not homogeneous throughout as we move vertically up from its surface, rather the atmosphere undergoes various changes and it is necessary to look at the vertical variations that exist within the Earth's atmospheric envelope to understand its dynamics properly and more precisely. The earth's atmosphere possesses a layered structure with each layer having different physical and chemical characters. The structure of the atmosphere can be understood on the basis of its temperature and chemical composition.

On the basis of temperature the atmosphere can be divided into four main layers viz. atmosphere are: troposphere, stratosphere, mesosphere and thermosphere.

Troposphere:

The layer of air immediately above the earth's surface is called the Troposphere. The word troposphere comprises of two words tropo and sphere meaning the mixing or the turning zone. As the name suggests the air in this zone circulates both vertically and horizontally convection currents, thus, redistributing heat and moisture across the globe. The thickness of the troposphere varies between 8 to 16 kilometers, and is least at poles and greatest at the equator. Troposphere is the most important layer of the atmosphere as all the weather phenomena take place in this zone. The characteristic feature of this layer is that temperature normally decreases with increasing altitude. The average rate at which temperatures within the troposphere decrease with altitude is called the normal lapse rate (or the environmental lapse rate); it amounts to 6.5°C per 1000 meters and the average temperature at the top of troposphere drops to -60°C. The altitude at which the temperature ceases to drop with increasing altitude is called the tropopause which marks the upper boundary of the troposphere.

Stratosphere:

The Stratosphere is the next layer that extends from the Tropopause up to 50 km above. The Stratosphere is vastly more dilute than the Troposphere and has almost no water vapor. The height of the bottom of the Stratosphere varies both with latitude and seasons, occurring between 8 to 16 km at the equator, 10 km at mid-latitudes and 8 km at the Poles. There are differing opinions about upper limit of the stratosphere; however the average upper limit has been taken to be 50 km. The temperature in the stratopause increases with increasing height and it reaches to 0°C at the height of 50km. though the stratosphere is devoid of any major weather activity; however there occur some weak winds and cirrus clouds in the lower part of this layer. This lower part of the stratosphere is very important for the life forms on the earth because the highest concentration of Ozone gas occurs here between the height of 15 and 35 km

which prevents the harmful ultraviolet rays of the sun from reaching to the earth. This zone between 15 and 35km is known as ozonosphere. At the upper boundary of the stratosphere the temperature ceases to decrease with increasing altitude which is called stratopause.

Mesosphere:

The third layer of the atmosphere is the mesosphere which begins at around 50 km and extends up to 85 km. Here, temperature decreases with increasing height. It is the coldest naturally occurring place on earth; a temperature minimum of -90° or lower, is reached at 85 km. the upper boundary of the mesosphere is called the mesopause which is usually at heights of 100 km, except at middle and high latitudes in summer where it descends down to heights of 85 km.

Thermosphere:

Beyond mesopause exists another layer of the earth's atmosphere known as the Thermosphere which begins at around 90 km and extends upto 1,000 km above the earth's surface. In the lower part of the thermosphere the temperature increases swiftly upto a height of 200–300 km. after this height the temperature increases steadily with increasing altitude and the temperature at the outermost limit of the thermosphere reaches upto 1700°C . The upper most boundary of the thermosphere is called the Thermopause. Thermosphere is divided into two layers viz. ionosphere and exosphere.

Ionosphere:

Ionosphere extends from 80 km to 640 km. there are a number of ionic sub-layers within this layer. These layers are D layer, E layer, F layer and G layer.

D layer extends from 60 km to 99 km. this layer reflects the low frequency radio waves but absorbs medium and high frequency radio waves. This layer disappears with sunset because it is associated with solar radiation.

E layer stretches for about 31 kilometers between 99 km and 130 km. this layer is reflects medium and high frequency radio waves back to the earth and this layer also disappears with sunset as it is produced by the interaction of UV radiations with nitrogen molecules.

Sporadic E layer begins at 130 km and extends upto 150 km and is created under special circumstances. This layer reflects very high frequency radio waves.

E_2 layer is generally found at a height of 150 km and is produced due to the interaction ultraviolet radiation with oxygen molecules hence this layer also disappears during night.

F layer is made up of two sub-layers collectively known as Appleton layer. The Appleton layer starts at 150 km and ends at around 380 km. this layer reflect medium and high frequency radio back to the earth.

G layer is the upper most layer of the ionosphere and extends from 38 km to 640 km. this layer probably exists throughout the day but it is not detectable during night.

Exosphere:

Exosphere is the top most layer of the atmosphere and extends beyond 640 km. this layer is highly rarified. The temperature in this very high and reaches upto 5568°C in its outer most limit. In this region the atoms and molecules escape into the space.

On the basis of chemical composition the atmosphere is divided into homosphere and heterosphere.

Homosphere:

Homosphere (from Greek: homo, same throughout) is the first layer of the atmosphere when it is divided vertically on the basis of chemical composition. This layer begins on the surface and extends to an altitude of 80 kilometers. In this layer, the gases maintain the same percent by volume as those listed in table 2.1. There are a few areas of concentration of specific gases, like the water vapor near Earth's surface and the ozone layer aloft, but for the most part the mixture is homogeneous. Other than

rapid decreases in pressure and density while ascending through this layer, this is essentially the same air that we breathe on the surface.

Heterosphere:

From an altitude of about 80 kilometers and reaching into the vacuum of outer space lies the heterosphere (from Greek: hetero, different). In this layer, atmospheric gases are no longer evenly mixed but begin to separate out into distinct sub layers of concentration. This separation of gases is caused by Earth's gravity in which heavier gases are pulled closer to the surface and the lighter gases drift farther outward. The regions of concentration and their corresponding gases occur in the following order: nitrogen gas (N₂) is the heaviest and therefore the lowermost, followed by atomic oxygen (O), then by helium (He), and finally atomic hydrogen (H), the lightest element that concentrates in the outermost region.

Solar Energy and the Atmosphere:

The sun is the primary source of energy, either directly or indirectly, for the entire Earth system. Earth does receive very small proportions of energy from other stars and from the interior of Earth itself (volcanoes and geysers provide certain amounts of heat energy); however, when compared with the amount received from the sun, these other sources are insignificant. Energy is emitted by the sun in the form of electromagnetic energy, which travels at the speed of light and it takes about 8.3 minutes for these waves to reach Earth's surface. The atmosphere affects the amount of solar radiation received on the surface of Earth because some energy is absorbed, some is reflected and some is refracted by the various gasses clouds particulate matter in the atmosphere. If we could remove the atmosphere from Earth, we would find that the solar energy striking the surface at a particular location for a particular time would be a constant and this constant value is known as solar constant.

Origin and evolution of oceans:

Evidence for the presence of water on Earth is found within minerals, known as zircon that can be found in Jack Hills, Australia. These zircons have oxygen isotopic compositions suggesting the presence of water on the Earth's surface about 4.4 billion years ago, about 150 million years after the formation of the earth. However these minerals do not tell us how much was the volume of water on Earth, so it is hard to speculate on the size of the oceans, but 3.8 billion years old sedimentary rocks called banded iron formation (BIF) that are exposed in southwest Greenland at a location called Isua. The very existence of the Isua BIF requires the presence of stable surface water, at least locally for the chemical deposition of the sedimentary components. These rocks were deposited in a somewhat analogous way to how limestones or cherts are deposited directly from seawater in modern marine environments. This suggests that the earth's oceans existed before 3.8 billion years ago. Studies of meteorites allow scientists to estimate that as much as 0.5% of the weight of the Earth is made up of water. This amount of water is more than enough to fill the world's oceans. The Earth's mantle is estimated to contain about six times as much water as in the oceans, so it's perfectly feasible that our surface water might have come from inside the Earth. It is believed that the Volcanic degassing of volatiles, including water vapor, occurred during the early stages of crustal formation and gave rise to the atmosphere. When the surface of the Earth had cooled to below 100° C (212° F), the hot water vapor in the atmosphere would have condensed to form the early oceans. The existence of 3.5-billion-year-old stromatolites is evidence of the activity of blue-green algae, and this fact indicates that the Earth's surface must have cooled to below 100° C by this time. Also, the presence of pillow structures in basalts of this age verifies the fact that these lavas were extruded under water, and this probably occurred around volcanic islands in the early oceans. Looking at geological evidences the earth science community is of the opinion that oceans developed on the earth well before four billion years before present.

The geometry and dynamics of the ocean basins over the past 200 million years are comprehensible within the framework of the plate tectonic theory. The ocean floor is continuously being recycled continuously by the destruction of the lithosphere at the oceanic trenches and the construction of new oceanic lithosphere at midoceanic ridges. Due to this continuous recycling the oceanic lithosphere is nowhere more than 180 million years old whereas we have the evidences of the continental lithosphere that more than four billion years old suggesting that dynamic than the continental lithosphere and evolves much faster.