Definitions and concept

Geology is the study of the planet Earth, its exterior as well as interior, its history and the processes that act upon it. Geology is also referred to as earth science and geoscience. The word geology comes from the Greek *geo*, "earth" and *logia*, "the study of." Geologist seek to understand how the earth formed and evolved into what it is today, as well as what made the earth capable of supporting life. Geologists study the changes that the earth has undergone as its physical, chemical, and biological systems have interacted during its 4.5 billion year history.

Geology is an important way of understanding the world around us, and it enables scientists to predict how our planet will behave. Scientists and other use geology to understand how geological events and earth's geological history affect people. For example, in terms of living with natural disasters and using the earth's natural resources. As the human population grows, more and more people live in areas exposed to natural geologic hazards, such as floods, earthquakes, tsunamis, volcanoes, and landslides. Some geologists use their knowledge to try to understand these natural hazards and forecast potential geologic events. They study the history of these events as recorded in rocks and try to determine when the next eruption or earthquake will occur. They also study the geologic record of climate change in order to help predict future changes. As human population grows, geologists' ability to locate fossil and mineral resources becomes more important.

For the field of forestry the science geology describes the different endogenous and exogenous geological processes that create suitable lands and physical environments for the plants. Geology also enables us to understand the processes of soil formation and guess and understand the composition of the soil by viewing its parent material and the processes that forms the soil. With the knowledge of geology of any particular area, we can get the information about the occurrence and movement of the groundwater and also helps in making use of it. By studying the prehistoric natural hazards it would be easier to understand the mechanism of the natural hazards and teaches the way by which we can protect our land of interest.

Components of geology

The field of geology includes sub fields that examine all of the earth's systems. Generally, these fields are divided into the two major categories of physical and historical geology.

1. Physical geology: physical geology can be subdivided into a number of disciplines according to the way geologists study the earth and which physical aspects they study.
    - Geophysics: geologists apply the concepts of physics to the study of the earth.

- Geochemistry: this is the application of chemistry to the study of earth, its materials, and the cycling of chemicals through its systems.
- Mineralogy and Petrology: the field of mineralogy deals the study of minerals and Petrology deals the study of rocks. Mineralogists and Petrologists study the origin, occurrence, structure, and history of rocks or minerals. They attempt to understand the physical, chemical, and less commonly, biological conditions under which geologic materials form.
- Structural geology: deals with the form, arrangement, and internal structure of rocks, including their history of deformation.
- Hydrogeology: is the study of groundwater and the geologic processes of surface water.
- Geomorphology: is the examination of development of present landforms.
- Marine geology: geology that is specific to the ocean environment.

2. Historical geology: historical geology focuses on the study of the evolution of earth and its life through time. Historical geology includes many sub fields.
    - Stratigraphy: is the study of the history of the earth's crust, particularly its stratified (layered) rocks. Stratigraphy is concerned with determining age relationships of rocks as well as their distribution in space and time.
    - Paleontology: is the study of ancient or fossil life.

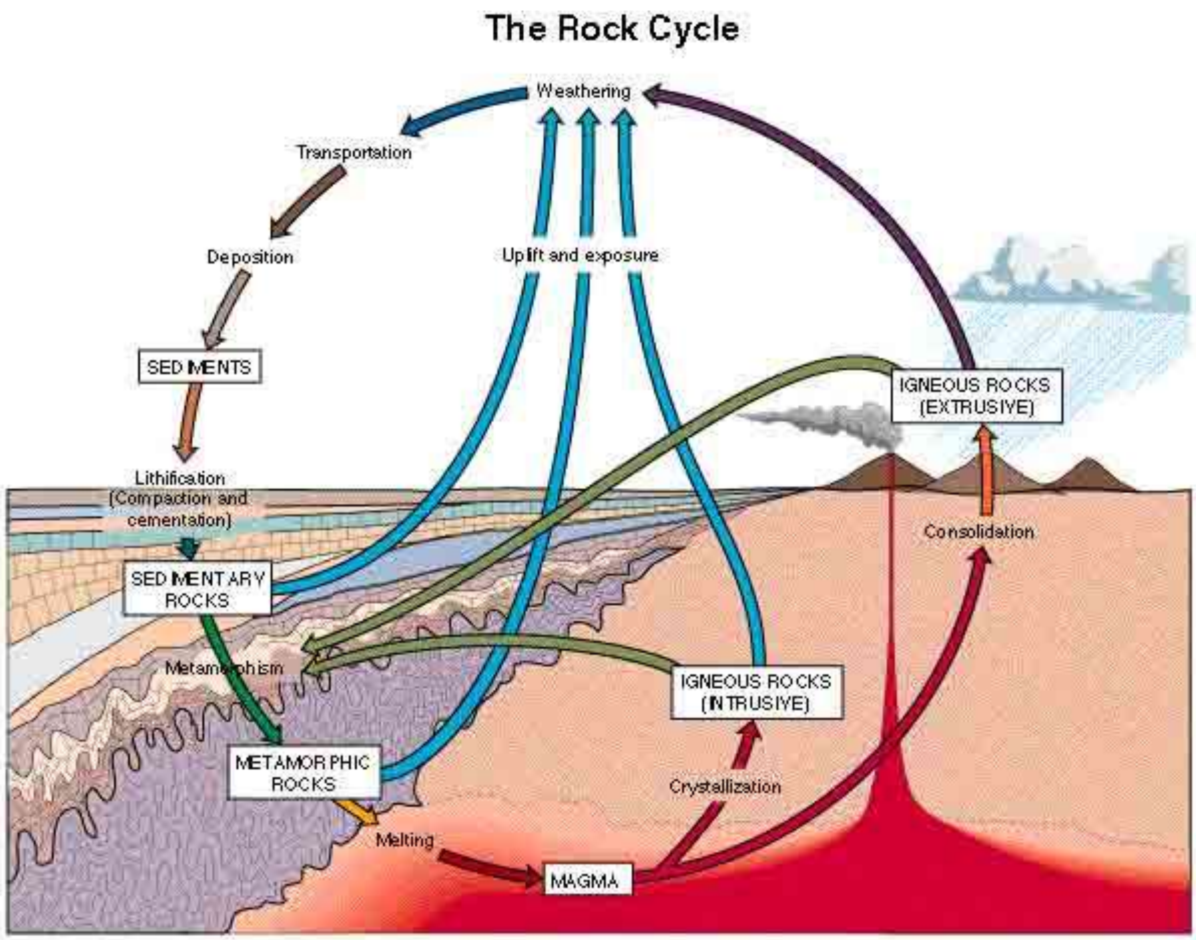
The geologic cycle

Hutton (1726-1797) was a gentleman farmer who set about attempting to apply the latest scientific methods in agriculture to his farm. He began to study rocks and the surface features of the Earth. Hutton proposed a whole new wad of looking at the world, which he named a "Theory of the Earth."

Hutton saw what was happening in the related activities we now know as the water cycle, or hydrologic cycle. The sun evaporates water from the oceans, clouds form, drift over the lands, and drop their water as rain or snow. The rainfall seeps into the ground or flows over its surface and eventually returns to the sea. The moisture attacks the bedrock, the continuous solid rock that locally forms the surface of the Earth. As a result, the bedrock breaks down into masses of loose particles called regolith. When the regolith becomes transported it is named sediment. When the flowing water returns to the sea, it carries with it a load of sediment particles and materials dissolved from the bedrock. The sediment is spread out in layers, or strata. The strata accumulate one after another with the oldest at the bottom.

Hutton was not the only person to realize how the rainfall affects the regolith; any alert farmer must have noticed how the fields lost soil during a heavy rainfall. But Hutton was the first person to work out the full implications of what happened to the eroded material. He realized that the loss of material from today's lands was being counterbalanced by accumulation of sediment in the sea that would become the lands of the future.

What Hutton did was to point out that the geologic cycle operates an important sub cycle that became known as the rock cycle. Geologist recognize three great groups of rocks: (1) igneous (2) sedimentary, and (3) metamorphic.



These differ in appearance, composition, and process of origin. Igneous rocks are formed by the solidification of molten material, or magma; molten material moves toward the Earth's surface and cools and hardens either beneath the surface or, if discharged from volcanoes as lava, on the surface. Sedimentary rocks are formed by the compression and cementing of sediment particles. The relationship between modern sediments and ancient strata of sedimentary bedrock was the cornerstone of Hutton's "Theory." He drew the significant conclusion that the continents being eroded today consist of layers of sedimentary materials that had been eroded from still-more-ancient continents. The third group, metamorphic rocks, consists of previously formed rocks that have undergone an extreme change in constitution caused by heat, pressure, of chemical action.

Internal Structure Of The Earth

To determine the composition and physical properties of the earth's interior is one of the most difficult problems faced by earth scientist. Direct observation of the interior of the earth is not possible due to the fact that the interior becomes hotter with depth, which is convincingly indicated by the volcanic eruptions. Besides, the deepest hole in the earth, a drill hole, is only about 8 km deep; this is quite negligible in comparison with the radius of the earth (6371.2 km). Since direct observation of the interior of the earth cannot be made conveniently. All the important sources of data on the structure of the earth are indirect and are logically derived and inferred from other evidences. The science or seismology has been used to interpret the internal structure of the earth.

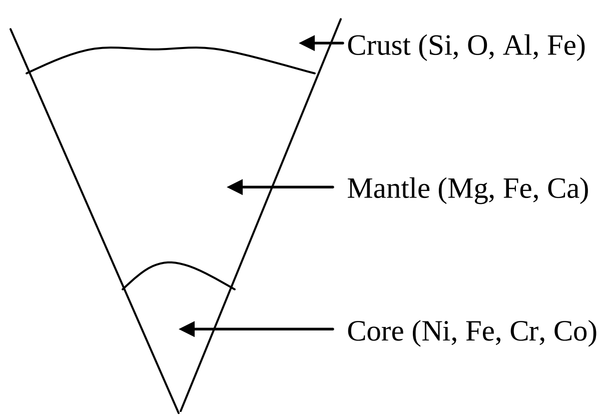
By the seismological study along with other data, it has been proved that the earth body comprises several layers of spherical shells of different chemical and mineralogical composition.

Broadly the earth interior has been divided in three major parts:

- Crust
- Mantle
- Core

Crust:

It is the uppermost shell of the earth that covers the rocks of the interior thinly. Its thickness over the oceanic areas is generally 5 to 10 km, whereas on the continental areas it is about 35 km and the thickness ranges from 55 to 70 km in orogenic belts. The Mohorovicic discontinuity marks its lower boundary. From the study of the shallow focus earthquakes and artificial seismic explosions, it has been inferred that there are two zones of crustal rocks beneath the continents, although only one occurs beneath the oceans. In the continental regions, underneath a zone of superficial sediments, the crust can be divided in to two layers, the upper layer called 'Sial' and the lower one 'Sima'. The



boundary between the sial and the sima is called the Conrad Discontinuity, which is located in the depth of 11 km.

Sial is also known as Upper Continental Crust. It consists of all types of rocks, igneous, sedimentary and metamorphic, which are exposed at the land surface. This layer is rich in silica and aluminum. The rocks in this layer are of granitic to granodioritic composition.

Sima is also known as Lower Continental Crust. Its thickness is about 22 km. It extends from the Conrad discontinuity up to the Mohorovicic discontinuity. This layer is rich in silica and magnesium and is basaltic in composition.

Mantle:
The second major part of the earth is the mantle, which is the source-region of most of the earth's internal energy and of forces responsible for ocean-floor spreading, continental drift, orogeny and major earthquakes. The mantle extends from below the Mohorovicic discontinuity up to a depth of 2900 km. Thus, its thickness is about 2856 km. It forms about 83 percent of the earth by volume and 68 percent by mass.

From Mohorovicic discontinuity to depth of 410 km there is gradual decrease in seismic velocity, which is known as Gutterberg layer. This Gutterberg layer together with upper crustal layer is called as lithosphere. The lithosphere is underlain by asthenosphere, which is also low seismic velocity layer. This indicates that in this layer the materials are somewhat plastic than the upper rigid lithosphere. This layer continues up to depth of 900-1000 km from where the lower part of upper mantle starts. From this point the seismic velocity rises sharply up to 11.4 km/ sec and rises gradually up and up.

Core:
Core is the innermost part of the earth. It is separated from the mantle by the Guttenberg-Weichert discontinuity and extends up to the very center of the earth. It constitutes around 17 percent of the volume and 34 percent of the mass of the earth. Since the S-waves don't pass through the outer core, they provide no information about the inner core. It only suggests that the core, at least in its outer part, is fluid-like in its character because it does not transmit the s-waves and because it retards the velocity of P-waves from 12.6 to 8.4 km/sec.

The core consists of three parts:

Outer core is considered to be in a state of homogeneous fluid. It does not transmit S-waves.

Middle core is a transition layer. The material is in a fluid to semi fluid state.

Inner core is assumed to be in a solid state, with a density of about 13×10^3 kg/m^3. It is believed to contain metallic nickel and iron and is called 'Nife'.

The origin of the earth

The Earth is the member of solar system so it can be believed that the origin of Earth is connected with that of the solar system.

All the principle theories, which have been advanced to explain the origin of Earth, have in common idea that the planets evolved from the sun. Regarding the origin of the Earth a number of theories have been put forward but none of them can be said to be perfectly correct. Some of the important theories explaining the origin of the earth are as follows:

There are mainly two schools of thoughts:

1. Catastrophic Theories: which believes the material was pulled out from the sun by an external force. The external force evoked was either a direct impact or a tidal force exerted by another stellar object in close proximity to the sun.
2. Evolutionary Theories: this school of thoughts postulates an ancestral nebula, which is a simply a cloud of gas containing highly dispersed small particles, from which, by some process of condensation or agglomeration, the discrete bodies of the solar system were ultimately formed.

We shall review a number of the hypotheses in chronological order of their statement. In 1749, the French philosopher Buffon proposed that during a collision with a passing comet, the substance of the planets was torn from the sun. Only a few years later (1755) a German philosopher Immanuel Kant, following an earlier proposal by Descartes, suggested that the solar system originated as a cloud of gas and dust, with a high concentration in the central region, which eventually became the sun. Thus the two-major schools of thought were born and came into direct conflict.

The nebular hypothesis:

Laplace Hypothesis: Kant's suggestion was taken up by the French astronomer Laplace, who in 1796 publishes the nebular hypothesis, according to which the sun was thought to be originally a hot rotating mass of gas and dust larger than the largest of the present planetary orbits. The nebula through its own gravitational attraction contracted in to a smaller volume and at the same time greatly increased the velocity of its rotation; at a certain critical point the centrifugal force of rotation at the equator of the nebula exactly balanced the gravitational force. Then, as the nebula continued to contract, the matter in the equatorial belt was left behind in the form of a ring, which split off, providing the substance out of which the outermost planet was formed. The same process, repeated, produced nebular rings for each planet, the entire system thus superficially resembling Saturn and its rings. Laplace supposed that the diffuse matter in each ring then condensed to form a single planet and more over that the planet in turn shrank and left behind rings, which became its satellites.

One serious objection raised against the Laplace hypothesis by the Scottish physicist Clerk Maxwell, relates to the distribution of angular momentum in the solar system. It was argued that if the nebular hypothesis of Laplace were correct, the sun should have enormously greater angular momentum than it does and should rotate about 200 times faster than it now does. As further objection to the nebular hypothesis it was difficult to find any reason for the intermittent contraction of the sun to produce rings, rather than a continuous contraction into a single mass, also if the rings were composed of highly heated gases, the gas molecules would readily escape the sun's gravitational field and rings would disintegrate.

Weizsacker's hypothesis: This is an early version of condensation hypothesis of planetary formation. In reviving Kant's suggestions von Weizsacker proposed that as the sun was formed it was surrounded by a cloud of gas and dust having a mass about one –tenth that of the sun. Gradually the cloud of gas and dust became concentrated into a greatly flattened disk in what is now the plane of the ecliptic. Temperatures within the disk of gas and dust would have been very high close to the sun, but decreasing rapidly toward the outer periphery. The low temperatures in the outer zone of the disk the volatile elements were easily and quickly condensed resulting in the growth of the great planets.

Proto-Planetary hypothesis of Kuiper: In 1951 G.P. Kuiper, an astronomer proposed modifications in Weizsacker's hypothesis. He suggested that there existed a flattened and slowly rotating disc-shaped solar nebula bulging out from the equator of the sun. This disc shaped nebula became internally unstable and broke up into smaller concentrations called "proto-planets", which later on collided and united to form bigger masses, which were the planets.

Urey's hypothesis: At about the same time that Kuiper was presenting his version of planetary development, the distinguished chemist and Nobel laureate Harold C. Urey was applying principles of chemistry to problems of the solar system, particularly through the investigation of the composition of meteorites. The following paragraphs are based largely on Urey's interpretations of events in the evolution of the solar system.

As contraction of the solar nebula began, any original turbulent motions, which its various parts might have had, were smoothed out by internal friction and transformed into a slow rotation of the entire mass. With contraction continuing, the conservation of angular momentum caused the angular velocity to increase, as the diameter of the nebula became smaller. Transfer of angular momentum from the central region, or solar mass, to the outer parts of the nebula that later formed the planets posed a vexing problem. It was then suggested that angular momentum might have been transferred outward through the nebula through the action of magnetic fields. This process has now achieved wide acceptance in the scientific community.

As contraction of the nebula continued and its rotational rate increased, the nebula took the form of a greatly flattened ellipsoid. The degree of flattening progressed until the nebula came to resemble a rather thin plate-like disk, with a solar mass concentrated at the center. It is estimated that about one-third of the nebular mass was in the disk, about two-thirds in the central condensation. During contraction those particles near the periphery whose centripetal acceleration exactly matched the gravitational acceleration of the total nebular mass were left behind in orbits of fixed size in the equatorial plane of the nebula. There was thus formed a thin nebular disk outside of the contracting mass. This disk comprised the matter from which planets were later formed.

The planetesimal hypothesis:

The sudden demise of Laplace's nebular hypothesis led quickly to the formulation in 1905 of a radically different explanation by two professors at the University of Chicago,T. C. Chamberlin, a geologist, and F. R. Moulton, an astronomer. They took up the suggestion made first by Buffon. The planetesimal hypothesis, as it was known, requires that a rapidly moving star once passed close to our sun, the mutual gravitational attraction of the two bodies raising two great tidal bulges on the sun. As a result there were ejected from opposite sides of the sun's surface a pair of curved arms of gaseous matter somewhat like the known solar prominences of today, but much larger. The total mass thus ejected was much greater than that of the present planets, but most of it fell back to thee sun's surface. That which remained in highly elliptical orbits about the sun condensed from the gaseous state into small solid particles, known as planetesimals. These in turn joined by collisions, the larger absorbing the smaller, to produce the planets. Gradually the space of the planetary orbits was swept clean of most of the planetesimals. They supposed that the planets thus grew by accretion of masses of many sizes. Although receiving the impacts of the planetesimals, the planets remained in the solid state throughout.
Since this hypothesis calls for a rare or special event in nature, having many of the aspects of an extraordinary accident, it dies not tend to be strong. Nevertheless, the concept of formation of planetesimals from a gaseous mass and their gathering together to form planets by gradual accretion is a valuable concept that has much to recommend it.

The tidal hypothesis:

Closely related in mechanism to the planetesimal hypothesis was an alternative proposal made shortly thereafter by the English astronomers Sir James Jeans and Sir Harold Jeffreys. They also supposed that a passing star had exerted a tidal pull upon the sun but that the effect was to cause a long filament of gases to be drawn from the sun. The outer part of the filament escaped into space, the inner part fell back into the sun and the middle part formed itself into a string of bead like masses, which condensed to form the planets.

New chemical evidence has now virtually ruled out the possibility that the planets were derived of matter from the sun's interior. Thermonuclear reactions within the sun's interior would have destroyed all deuterium (an isotope of hydrogen) at an early stage in its history as a star. Hence our earth and meteorites would not now possess deuterium in their compositions.

All ideas concerning the origin of the Earth and the solar system have their problems, and new discoveries often add to the demerits to the theories. Thus, origin of the solar system continues to be a problem and even the most modern theories contain many points that need verification.

Plate tectonics

The history of plate tectonics begins as far back as 1620; Francis Bacon spotted that west coast of Africa and the west coast of South America looked as if they would fit together, like a pieces of jigsaw. In 1912, Alfred Wegner, a young German Meteorologist, published a theory to explain why the Earth looked like a huge jigsaw. Wegner asserted that many surprising and apparently disconnected facts from geology, climatology, biology, and paleontology could be explained by only one idea: that the continents had, until about 200 million years ago, been united in a single land mass which has since broken apart. He called his super continent, Pangaea. Some of the proposed evidences were:

- Same type of fossils was found on the both coast, South Africa and Brazil.
- Rocks of both coasts were very similar, both in age and in structures.
- Coal has been found in Antarctica and Britain in present day. But these places have cold climate and coal deposits in warm conditions only. So both places must be nearer to equator in past days.

■ **FIGURE 7.4** Bullard's fit of South America and Africa. The outlines correspond to the 914-m bathymetric contour. Light red shaded areas represent gaps and gray shaded areas represent overlaps in the fit.

Whereas Wagener's compilation of the evidence for continental drift was impressive, it was largely circumstantial. Wagener believed that the continents had moved, but he was not able to propose a satisfactory mechanism, which could move them. So the theory of continental drift did not receive wide acceptance among geoscientist.

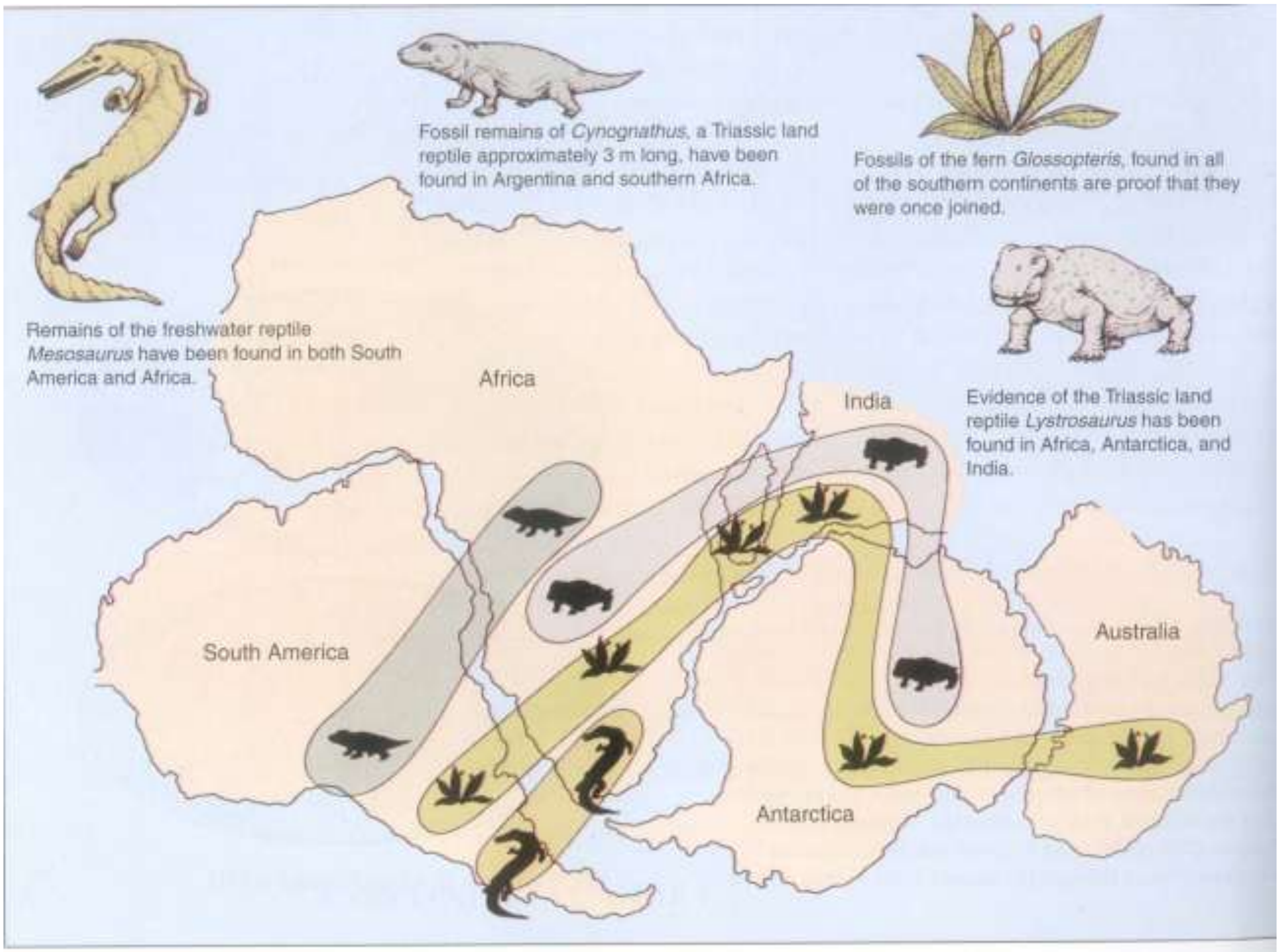
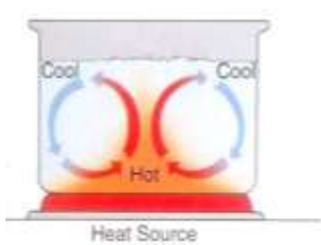
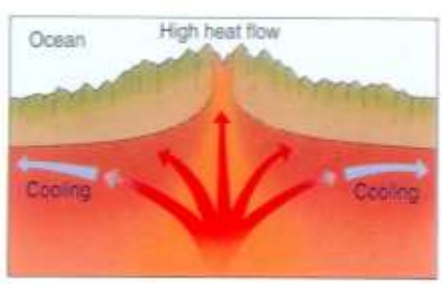


FIGURE 17.2 **Paleontologic evidence of continental drift** can be appreciated by considering the distribution of some fossil plants and animals found in South America, Africa, Madagascar, India, Antarctica, and Australia. *Mesosaurus*, a Permian freshwater reptile, is found in both Brazil and South Africa. *Glossopteris*, a fossil fern, is found on all of the southern continents in the zone shown on the map. *Lystrosaurus*, a Triassic land reptile, is found in South Africa, South America, India, and Antarctica. *Cynognathus*, an older Triassic reptile, is found in Argentina and South Africa. *(Modified from L. Motz)*

In 1928 an English geologist Arthur Holms elaborated on the Wagner's hypothesis with an example of thermal convection current of water on beaker when the water is heated.





He related this idea with the earth structure, in which interior portion of the earth acts as a source of heat, magma of mantle moves upward and downward in the circular path following the thermal convection, which results the movement of the thin earth's crust. Not until the 1960s Holmes idea receive any attention. After more discoveries by Harry Hess (1962) and R. Dietz (1961), the ideas of Wagner and Holmes receive some attention. Harry Hess argued, on his "Sea floor spreading theory" that the deep-sea floor had been and still is, moving. He proposed that the deep-sea floor is locked tightly to the mantle and thus the ocean floor could move along with the mantle without disturbing the deep-sea sediments. Hess also rejuvenated the idea, originally proposed in 1928 by Holmes, that the driving force for moving the continents consisted of convection currents within the mantle. During the early 1960s, when the evidence in support of continental displacement was becoming stronger, the idea of convection currents in the solid mantle was not thought to be outrageous after all.

Now days the concept of Plate tectonics is a worldwide network of moving lithospheric plates. The American scientists Heess and dietz formulated the concept. Plate tectonics discuss the movement of lithospheric plates and the geological activities associated with them.

Features of Plate tectonics

Plate is a large rigid plate, which moves slowly over the asthenosphere and has thickness 0-10 km at ridges and 100-150 km at other places. Plates are of continental dimensions. There are numbers of plates are considered by different geologists. But in broadly Le Pichon thought six major plates could be seen on earth with numbers of small plates.

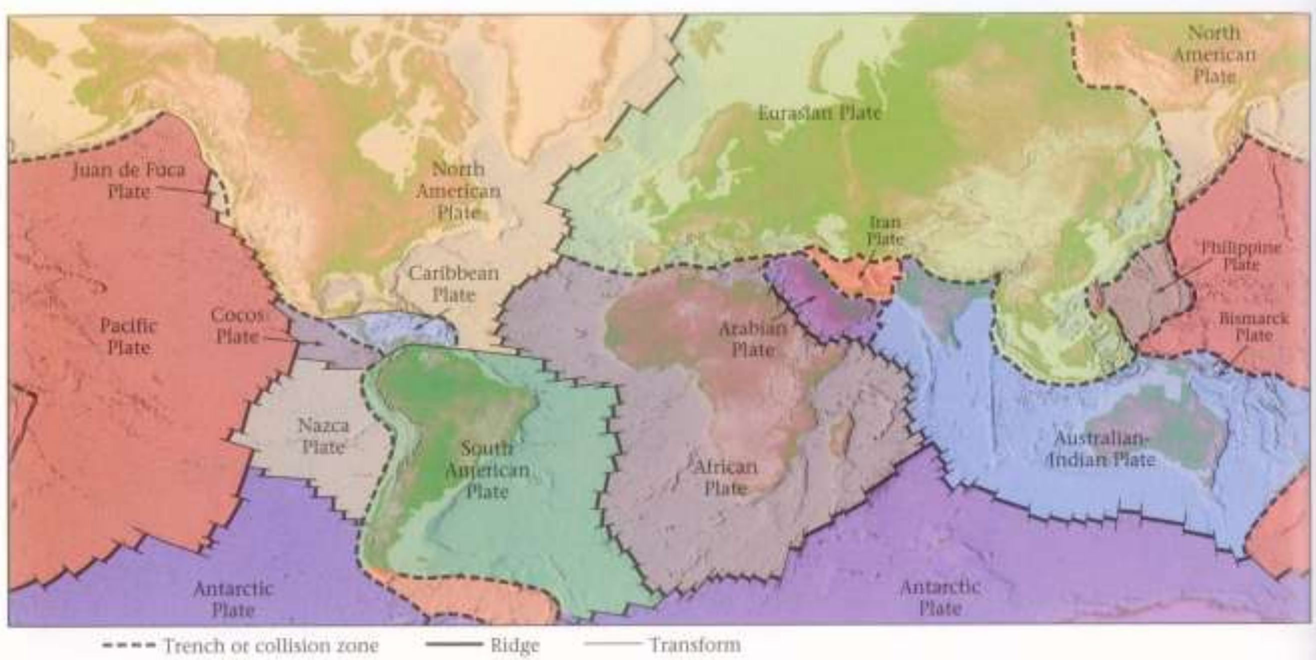


FIGURE 4.3 The major plates making up the lithosphere. Note that some plates are all ocean floor, while some contain both continents and oceans. Thus, some plate boundaries lie along continental margins (coasts), while others do not. For example, the eastern border of South America is not a plate boundary, but the western edge is.

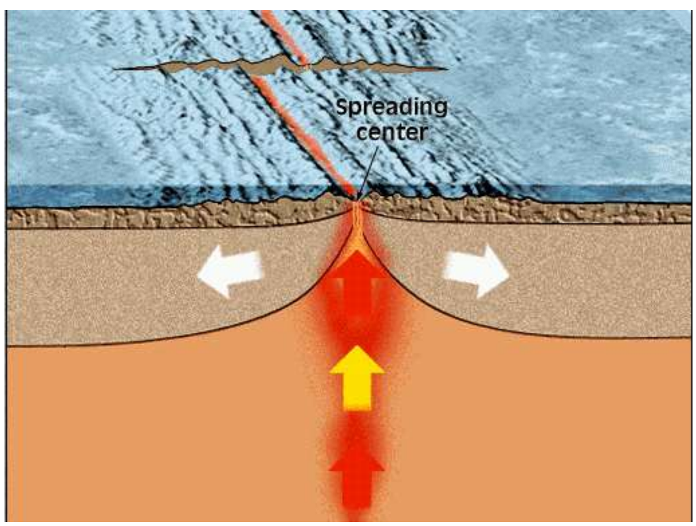
1. The Pacific plate
2. The American plate
3. The African plate
4. The Eurasian plate
5. The Indian plate
6. The Antarctic plate

The plate may contain continental as well as oceanic surface. Of six major plates, five contain continents or parts of the continents in the lithosphere; only the Pacific plate is made up mostly of sea floor. Small plates are some have continent only and some have ocean floor only. The plates are in continuous motion with respect to each other ad to the earth's axis of rotation. All seismic, volcanic and tectonic activity is localized around the plate margin. Plate interior generally don't have such process. Plates move with velocities ranging from 1 to 6 cm per year. Plates move away from one another, past one another or towards one another. Plate boundaries are the surface traces of the zone of motion between two plates. Plate margin is the marginal part of a particular plate. Two plates margin meet at a common plate boundary, where three plate boundaries meet, it is termed as a triple-junction.

Plate boundaries

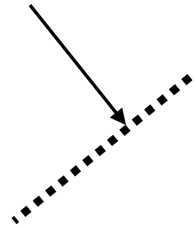
Plate boundaries are the sites of intense geologic activities, which are mainly due to the movement plates. There are mainly three types of plate boundaries.

1. Constructive (divergence) plate boundaries: two plates are in motion away from each other. As result of which a fissure develops, upwelling hot molten rock materials to form new plate from mantle. The fissure represents the zone of spreading and upwelling of material from mantle and construction of new crust, the boundary is constructive or divergent as the two plates move away from each other.



2. Destructive (convergence) plate boundaries: this is a zone along which two plates are in motion towards each other causing one plate to go beneath the other. The denser plate sinks in a process called subduction. Oceanic plate generally subduct due to its higher density than that of the continental crust. Similarly, plates collide each other forming mountain ranges. Nepal Himalayas lies in this type of boundary.

Destructive (convergence)



3. Conservative (transform fault) plate boundaries: these are the boundaries where two plates slide past one another along a single fault of a group of parallel faults. The motion of the plate is strike slip along the fault, resulting what is called a transcurrent or transform fault. These are also called conservative or shear margins; the plates neither gain nor lose surface areas.

Importance of Plate tectonic theory

The theory of plate tectonics is now able to explain the different phenomenon like continental drift, sea floor spreading, orogeny (mountain building) activity, earthquake, volcanism and many other processes that were happened and are happening on and within the earth’s surface and lithosphere.

Orogenic belts (convergent boundaries), a result of plate motions, are the preferred geological habitats of plutons composed of granitic rocks or of intermediate rocks. Thus, orogenic belts are places where one would start to search for many natural resources. Primary deposits of tin or tungsten that may have been deposited with granite, and many kinds of hydrothermal deposits that may be associated with felsic or internediate rocks. These include deposits of copper, gold, silver, lead, zinc and many other metals. Many ore deposits of metallic minerals (chromite, nickel, platinum, and magnetite) are associated with mafic igneous rocks that formed at a spreading ridge on the sea floor.

Petrology is a science that deals with the study of various aspects of rock as: mode of formation, composition, structure, texture, classification, and occurrence.

Rock is a naturally forming assemblage or aggregate of minerals in consolidated or compacted form. A rock may be mono-mineralic (e.g. Dunite) or poly-mineralic (e.g. Granite). According to the mode of formation the rocks are classified in to three major categories: Igneous, Sedimentary, Metamorphic. The natural processes of magmatism, sedimentation, and metamorphism forms these rocks respectively.

1. Igneous rocks: - Igneous rocks are formed from molten rock or magma, which has originated well below the earth's surface, has ascended towards the surface, and has consolidated or crystallized as solid rock either underneath the surface or above it; accordingly they are classified in to two major groups:

a) Intrusive or plutonic rocks: These are due to the consolidation of magma underneath the surface of the earth.

b) Extrusive or volcanic rocks: These are due to the consolidation of magna above the surface of the earth.

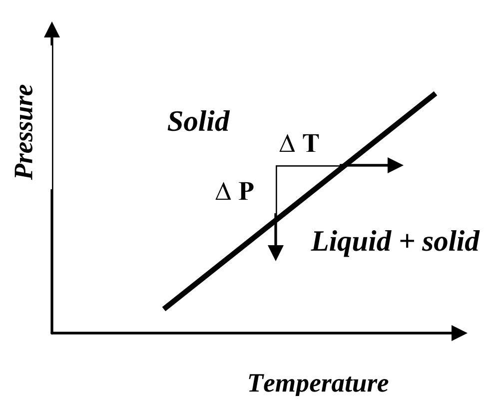
Important features of igneous rocks:

- Generally hard massive compact with interlocking grains.
- Absence of fossils
- Absence of bedding planes
- Enclosing rocks are baked

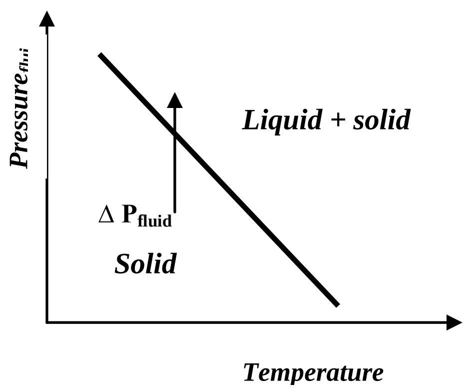
Origin of magma:

Magma is a naturally occurring, hot, mobile molten material or liquid rock existing below the earth surface. It is a mixture of molten rocks and dissolved different gases. Suspended solids such as crystals and rock fragments may or may not be included. The melting of rock material at higher temperature forms magma. Some factors that cause the melting of rocks are:

- Increase in temperature: the temperature may increase in depth below the earth surface due to geothermal gradient (increase in temperature with increasing depth), radioactive decaying (decaying of the localized concentration of the radioactive element onto daughter element produce thermal energy), and friction between converging plates; and the increased temperature becomes the causing factor for the melting of the rocks forming the magma.



- Decrease in lithostatic (overburden) pressure: if the overburden pressure (load) of any rock material is lowered due to some reason (erosion, mountain building process), the existing temperature could be high enough to melt the rock and hence forming the magma.
- Addition of fluids and increasing the fluid pressure: it has been verified by experimentally that the melting point of silicate rocks decreases with increasing the fluid pressure. Thus in a certain system of fixed composition and temperature, by addition of the fluids (especially water) and thereby increasing the fluid pressure the system (rocks) starts to melt.



Texture of Igneous rocks

Texture is defined as the geometrical relationship among the constituents of rock (minerals, grains). This is the pattern, fashion, or appearance shown by the rock due to the specific arrangement of rock constituents.

Igneous rock texture is described on the basis of:

a) Crystallanity (degree of crystallization): this is the relative proportion of glass and crystals in igneous rocks ranging from entirely crystal to entirely glass. Crystallanity is further described as:

- Hollocrystalline: when an igneous rock is made up of coarse mineral grains only i.e. 100% crystals
- Hypocrystalline: when a rock contains both crystalline as well as glassy matter in variable proportion.
- Hollohyaline: when igneous rock contains 100% glassy matter.

b) Granularity (size of crystal grains): this is the grain size of crystals present in the igneous rocks. Granularity also can be described on the basis of visual observation of mineral grains of rock that can be seen or not with naked eye. And on the basis of measurement of grain size, there are following texture.
   - ♣ Phneritic: all crystals of the principal minerals can be distinguished by naked eye. This group of grain size is further divided into:
     - Coarse grained: if size (diameter) of individual grain is greater than 5 mm.
     - Medium grained: if size (diameter) of individual grain is between 1 to 5 mm.
     - Fine grained: if size (diameter) of individual grain is less than 1 mm.
   - ♣ Aphanitic: all crystals other than any phanerocrystals present are distinguished by the naked eye. This group of grain size is further divided into:
     - Microcrystalline: if the individual crystal can be visualized under microscope.
     - Cryptocrystalline: if the individual crystal cannot be visualized under microscope.

c) Crystal shape: texture of igneous rocks can also be described on the basis of shape of mineral grains of rock. Term indicating the quality of the development of faces on crystals:
   - ♣ Euhedral: crystals completely bounded by its characteristc faces. these are also known as idiomorphic or automorphic crystals.
   - ♣ Sub-hedral: crystal bounded by only some of its characteristic face. These are also known as hypidiomorphic or hypautomorphic crystals.
   - ♣ Anhedral: crystal lack of any of its characteristics faces. These are also known as allotromorphic of xeomorphic.

d) Mutual relationship among crystal grains: it refers to herelative size, shpe and dimensions of crystals of rock and their relation to one another, which may be as follows:
   - ♣ Equigranular: in this texture, development on the uniform size of the crystals occurred.
   - ♣ Inequigranular: if the grain size of rock shows a marked difference from grain to grain, this is known as inequigranular texture. This can be described as following types:
     - Porphyritic texture: relatively large crystals (phenocrysts) are surrounded by fine-grained crystals of groundmass.
     - Poikilitic texture: relatively large crystals of one minerals enclose numerous smaller crystals of one or more other minerals.
     - Seriate texture: crystal of the principal mineral show a continuous range of crystal size.

Classification of Igneous rocks

Igneous rocks show great variations both in chemical and mineralogical composition as well as textural characteristics, there is no general agreement among the petrologists. Different classification have been proposed on the basis of:

a) Mineralogical composition:

The minerals occurring in igneous rocks may be broadly classified in to felsic and mafic varieties. Felsic minerals constitute feldspar, feldspathoid and silica and mafic minerals constitute ferromagnesian minerals like biotite, pyroxene amphiboles etc. Felsic minerals are light in colour, low melting point, and low specific gravity where as the mafic minerals are dark coloured, higher sp. Gravity, higher melting point. At the later date of international union of geological science (IUGS) adopted and internationally accepted comprehensive system for igneous rock classification. To classify a rock correctly the mineral composition, the percentage of five minerals must be determine: quartz, plagioclase, alkali feldspar, ferromagnesian and felspathoids. Then the determined percentage of minerals is plotted on QAP (quartz, alkali feldspar, plagioclase) and classified accordingly.

The rocks containing more than 90% mafic minerals are classified as:

- Peridotite: mainly olivine (40-100%), remaining pyroxene and/or hornblende
- Dunite: 90-100% olivine, remainder pyroxene
- Pyroxenite: 90-100% pyroxene, remainder olivine and hornblende
- Hornblendite: 90-100% hornblende, remainder olivine and pyroxene

Still IUGS classificaton cann't cover all the igneous rocks. So, some rocks are classified on the basis of texture.

- Pegmatite: very coarse grained and having granitic composition
- Obsidian: dark colored volcanic glass
- Tuff: compacted deposit of volcanic ash
- Breccias: tuff containing large angular fragments.

b) Chemical composition:

Based on the silica (SiO_2) percentage on the chemical composition of the rock the igneous rock can be classified in to:

Percentage of SiO_2	*rock classification*	*examples*
>66	acidic	Granite, quartz diorite
52-66	intermediate	granodiorite
45-52	basic	diorite, gabbro, basalt
<45	ultra basic	peridotite, dunite

Another classification can be made based on silica saturation:
Silica-over saturated: in the chemical composition of the rock the silica is so rich, the excess of silica crystallize as quartz (mineral).

Silica saturated: the rocks have just sufficient silica to form the stable silicate minerals, but no free quartz.

Silica under saturated: the rocks contain insufficient silica and minerals like olivine, nepheline, luecite are present.

c) Textural characteristics:
It is mostly based on the cooling history of the magma and modes of occurrence of these rocks. Accordingly:

i) *Plutonic:* these rocks are formed under deep-seated conditions, where the temperature and pressure are very high and the rate of cooling is very slow. Hence their texture is holocrystalline and coarse.

ii) *Hypo basal:* this group includes the rocks, which solidifies intermediate position in the crust between plutonic and volcanic rocks. Their texture is usually microcrystalline.

iii) *Volcanic:* these rocks are formed on the surface of the earth and due to rapid rate of cooling their texture become holohyaline and fine grained.

Forms of Igneous rocks

The magma during its movement up o surface sometimes gets successful to melt and disturb the existing adjoining rocks and sometimes it may fail to do it. When magma is unable to disturb and cut across the existing rocks it may get cooled and solidified within the fissures or cavities prevailing in the existing rocks. Such intrusions, which are not influenced by the structural features of intruded rocks, are known as concordant bodies. If the intrusive magma solidifies after disturbing and cutting across the existing intruded rocks by melting or keeping aside are known as discordant bodies.

Types of concordant bodies

Sill: when magma is pushed into the existing bedding/foliation of existing rocks and solidified in the form of a thin sheet is called sill.
Phacolith: when magma is under low pressure, it will not exert more pressure to make space or way for itself. In such cases the magma may be pushed into existing crests and troughs of a fold in the existing rock and solidified there. These forms are known as phacolith.
Laccolith: when the magma injects layers of the existing rocks but unable to spread length and width wise for greater distance due to high viscosity it may force the layers of

rocks upwards in the form of dome or arch. The magma confining and solidified in such shaped mass is called laccolith.

Types of Discordant bodies:

Dyke: when the magma is forced through the vertical or nearly vertical cracks or fissures in the existing rock and gets solidified as a wall like structure is called dyke.
Volcanic neck: when magma is forced into the holes of inactive volcanoes and gets swolidified in the form of pipe is called volcanic neck.
Batholith: when magma moving under high pressure, it fills up a large space in the existing rocks by the melting them away or keeping side. The huge mass of igneous is called batholith.

2. Sedimentary rocks: - sedimentary rocks are formed from the process of sedimentation which involves the accumulation and compaction of either (a) fragments from pre-existing rocks which have been disintegrated by weathering and erosion (e.g. sandstone), (mechanical sedimentation); (b) organic debris such as shell fragments of dead plants (e.g. coal, peat etc.), (biogenic or organic sedimentation); (c) material dissolved in surface water or ground water, which is precipitated in the condition of over saturation (e.g. limestone), (chemical sedimentation).

The process of sedimentation involves:

- Formation of sediments: by the means of weathering/erosion/precipitation
- Deposition of sediments: when the velocity of transporting agents is checked
- Compaction: involves the decrease in volume of the accumulated sediments due to load of the overlying sediments
- Lithification: this involves the change of loose sediments into rock, and involves:
    - Petrification: the sediments gets converted into massive and hard form, sometimes by replacement
    - Cementation: binding of loose sediments with fine materials
    - Diagenesis: growth of new minerals to adjust the pressure.

Important features of sedimentary rocks:

- Generally soft, stratified
- Fossils common
- Stratification, lamination, cross bedding, ripple marks, mud-cracks etc. are the usual structures.

Texture of sedimentary rocks

On the basis of sedimentation Process (either mechanical, chemical or organic) that formed the sedimentary rock the texture of sedimentary rocks can be classified as:

a) Clastic texture:

Clastic texture is shown by the rock that are formed by the mechanical sedimentation precess. The clastic texture can be further divided on the basis of:

- Size of grain
  Coarse grained: sediment or clast size (diameter) > 5mm
  Medium grained: sediment or clast size (diameter) 1- 5mm
  Fine grained: sediment or clast size (diameter) <1 mm

- Shape of grains (clasts): the shape of grains (clast) is described on the basis of degree of roundness
  Rounded: if the grains or clasts are of round shape.
  Sub-rounded: if the grains or clasts are of partially or semi-rounded shape.
  Angular: if the grains or clasts are of angular shape.

- Packing of grains:

Openly packed: ***during the accumulation of sediment if the clasts or grains are packed loosely***

Compactly packed: during the accumulation of sediment if the clasts or grains are packed tightly or compactly

- Sorting of grains: it is described on the basis of uniformity of sediments or clasts or rock
  Poorly sorted: if rock has different sized grains
  Well sorted: if rock has uniform sized grains
- Type of support: it is described on the basis of proportion of the fine clasts or grains (matrix) or coarser clasts or grains
  Clast supported: if the rock contains maximum proportion of coarser clasts than 2 mm in size
  Matrix supported: if the rock contains maximum proportion of fine clasts or grains than 2 mm in size

b) Non-clastic texture: non-clastic texture is described on the basis of inspection of size of sediments under the petrological microscope and described as:
   - *Macrocrystalline or sparry:* if size of sediments of rock are > 20 micrometer
   - *Microcrystalline:* if size of sediments of rock are < 20 micrometer
   - *Cryptocrystalline:* if individual grains of rock cannot be distinguished under microscope.

Sedimentary structures

Sedimentary rocks possess definite physical characteristics and display certain features/structures, which make them readily distinguishable from other types of rocks. Some of important structures of sedimentary rocks are:

- Stratification (bedding): the most characteristic feature of sedimentary rocks is their tendency to occur in strata or beds. Each stratum or bed is separated by a bedding plane, which marks the top of one bed and the bottom of the bed next above it. Generally the grains of sediments within a particular stratum are identical and uniform but sometimes it becomes rather different. On such cases, a different naming is given for those type of stratification as, graded bedding, rhythmic bedding and cross bedding. *Graded bedding* occurs when material sorts itself out after quick deposition with the heavy material at the bottom. The deposition of coarse to fine materials from bottom to top and forming a single layer and so on on next cycle. *The rhythmic bedding* consists of alternating parallel layers having different properties. *Cross bedding* consists of sets of lamina or beds that are inclined relative to one another within layers. Cross bedding is very common in sand dunes and river sediment.
- Imbrications of pebbles: elongated pebbles, cobbles and boulders of river generally stack on each other to form imbrications during deposition and it results imbricate pebbles.
- Raindrop marks: these are pits created by raindrops. If present, this suggests that the sediment was exposed to the surface.
- Ripple marks: ripple marks are found in bedding plane of shallow water deposition. They are formed by waves or winds piling up the sediment into long ridges.
- Mud cracks: it is not uncommon to find mud cracks that have formed on the bottom of dried-up lakes, ponds, paddy fields, or stream beds. The cracks are formed because of shrinkage of the sediment during drying. In cross section the mud cracks tend to be wedge shaped.
- Load casts: these are bulbous protrusions that are formed when compaction causes sediment to be pushed downward into softer sediment.
- Flute casts (sole marks): flutes are elongated depressions that are formed on the bottom as the current erodes.
- Tracks and trails: these features are imprints of organisms moving across the sediment as they walk, crawl, or drag their body parts through the sediment. Such structures are also called trace fossils.

Classification of sedimentary rocks

The sedimentary rocks can be broadly classified in to two categories: clastic and non clastic

a) **<u>Clastic rocks</u>**: these are detrital or fragmental rocks and are deposited by mechanical means of the geological agents. On the basis of mode of transportation and grain size, the clastic rocks are classified as follows:

<u>Rudaceous rocks</u>: very coarse-grained rocks where the size of the grains is those of boulders. These are transported in traction i.e. by rolling or creeping, e.g. conglomerate.

<u>Arenaceous rocks</u>: these rocks consist chiefly particles of sand size. They are transported in saltation, e.g. sandstone, arkose, greywacke etc.

<u>Argillaceous rocks</u>: these are made up of clay particles, usually transported in suspension, e.g. clay stone, mudstone, shale etc.

b) **<u>Nonclastic rocks</u>**: these are formed due to chemical precipitation as well as by biological means. Thus they are of two types:

i) Chemically deposited:

- Evaporates: it is only due to evaporation and the deposits are like salt and gypsum.
- Siliceous deposits like chert, flint, siliceous sinter etc.
- Calcareous and carbonates like limestone, dolomete, calcsinter or travertine.
- Ferruginous deposits like iron salts, hematite, goethite, siderite etc.

ii) Organic sediments: these are the products of accumulation of organic matter preserved under suitable conditions. A rock of organic origin may be built up directly from the beginning as a quite solid material as in the case of coral rocks and algal limestones. They are of:

- *Siliceous* (some plant organism like radiolarian ooze, diotoms are plant organisms which secrete silica)
- *Calcareous*
- *Phosphatic* (calcium phosphate is used up by some fishes or brachiopods, remains of those)
- *Ferruginous* (by activities of bacteria)
- *Carbonaceous* (by burial of plant species)

c) Metamorphic rocks: - These rocks are formed from pre-existing rocks of any type, which have been subjected to increases of temperature or pressure or both; such that the rocks shows the mineralogical and structural adjustment of existing minerals and structures under the influence of temperature, pressure and chemically active solutions. The process by which the rocks show the readjustment under the influence of described factors (factors of metamorphism) is known as the process of metamorphism.

Important features of metamorphic rocks:

- Generally hard, interlocking grains
- Foliated, gneissose, schistose, granulose, slaty etc. are the common structures.
- Fossils are non-or rarely preserved in rocks of sedimentary rocks.

Types of metamorphism

- Regional metamorphism: this type of metamorphism is also known as dynamo-thermal metamorphism. Temperature and pressure both are the chief factors for the metamorphism. Regional metamorphism occurs over larger areas.
- Cataclastic metamorphism: this type of metamorphism is also known as dynamic metamorphism. Pressure is the chief factor for the metamorphism. According to the state and nature of the prevailing pressure, this type of metamorphism is further divided as: *cataclastic metamorphism*, if the dynamic pressure is the chief factor and *burial metamorphism*, if the static pressure is the chief factor for the metamorphism.
- Contact metamorphism: this type of metamorphism is also known as thermal metamorphism. Temperature is the chief factor for the metamorphism. Contact metamorphism occurs adjacent to igneous intrusion and results from affect of high temperatures of igneous intrusion.
- Metasomatism: the chemically active solution is the chief factor for the metamorphism. If the chemically active hydrothermal solution is passed through the pre-existing rocks, then the hydrothermal solution will react with the pre-existing minerals and structures forming newer ones. This process is known as the process of metasomatism.

Texture of metamorphic rocks

Broadly the metamorphic rock texture can be described under the visual inspection as *phaneritic*, if the individual grains can be visualized with naked eye and *aphanitic*, if the individual grains cannot be visualized with naked eyes. Furthermore, the texture of metamorphic rock is described on the basis of the mutual relationship between the mineral grain sizes as:

- *Isotropic texture (granoblastic / crystalloblastic):* grains of equal dimension exhibit this type of texture. If crystals of grains are completely bounded by its characteristc faces then that type of texture is *idioblastic texture* and when crystal lack of any of its characteristics faces then theat type of texture is *xenoblastic texture.*
- *Anisotropic texture:* platy or acicular grains exhibit this type of texture. Acicular texture is further described as:

Planner (lepidoblastic): platy mineral grains define this type of texture
Linear (nematoblastic): acicular mineral grains define this type of texture
Planner-linear:

- *Relict texture:* relict texture of metamorphic rock indicates the texture of original rock that has been retained by the rock in spite of metamorphic changes. This type of texture is described as:
  Porphyroblastic: relatively large crystals (pheneroblasts) are surrounded by fine-grained crystals of groundmass
  Poikiloblastic: relatively large crystals of one minerals enclose numerous smaller crystals of one or more other minerals
- *Mylonitic texture:* this is very fine-grained (aphanitic) texture produced by intense deformation and the pulverization of the material during the dynamic metamorphism process.

Structure of metamorphic rock

Structure of metamorphic rock can also be referred as the metamorphic rock cleavage. Among the important types of metamorphic structure, the following are very common:

- Foliated structure: this type of structure is defined by the segregation of minerals into layers and may be of following types:
  Slaty structure: it is due to parallel arrangement of such minerals in a rock that are highly cleavable in nature. The slaty structure may be smooth palnner or may be of slightly undulated.
  Schistose structure: it is a structurall feature that is made up of parallel or sub-parallel layers of platy and flaky minerals.
- Banded structure (weakly foliated structure): this type of structure is formed by the segregation of minerals in distinct and alternating bands of granular (light colored) minerals and flaky or needle shaped (dark colored) minerals. This type of structure is also known as the *gneissose structure*.
- Non-foliated structure (granulose structure): in this type of structure, under visual inspection, there is no distinct segregation of minerals on layers or bands but there is the uniform distribution of the mineral grains.

Classification of Metamorphic rocks

Classification of metamorphic rocks can be done depending upon different factors. They are:

a) The parent rocks: - if the parent rock of metamorphic rock is of igneous origin, have subsequently undergone some or other metamorphic changes, the resulting rock is known as ortho-metamorphic rock (ortho-gneiss, ortho- schists etc.)

When sedimentary rocks undergo metamorphic changes, the resulting rocks are said to be para- metamorphic rocks (para- gneiss, para-schists etc.)

b) Development of foliation plane: - on this basis, the scheme of classification of metamorphic rocks has three subdivisions: (1) strongly foliated rocks, (2) weakly foliated rocks and (3) non- foliated rocks.

Strongly foliated rocks	*weakly foliated rocks*	*non-foliated rocks*	
Slate	Gneiss	Granofels	Quartzite
Phyllite	Migmatite	Amphibolite	Marble
Schist	Mylonite	Serpentinite	Argillite
		Greenschist	Skarn
		Hornfels	

c) The inferred P-T condition (degree of metamorphism): - on this basis the metamorphic rocks can be categorized in to:

(1) Low grade metamorphic rocks, e.g. slate, Phyllite, meta-sandstone
(2) Medium grade metamorphic rocks e.g. schist, quartzite, marble and
(3) High grade metamorphic rocks e.g. gneiss, migmatite etc.

Minerals:

Minerals are naturally occurring solid, inorganic substance, which has definite chemical composition, fixed crystal structure and diagnostic physical properties such as color, luster, hardness, specific gravity etc. All mineral possesses certain physical properties which are direct result of chemical and physical characteristics.

Physical properties of minerals:

1. Color: it is the first and easily observed property of the mineral. For many, it is characteristics and serves as a distinguishing criterion.

   e.g. white: magnesite, talc
   blue: azurite, covellite
   green: malachite, olivine
   yellow: sulphur, chalcopyrite
   red: realgar, cinnabar etc.

2. Streak: the color of a finely powered mineral is known as its streak. Although the color of mineral may vary, but the streak is usually constant, and is thus useful in mineral identification.

   e. g. siderite(blue mineral color) = white streak color
   hematite (steel gray) = cherry red
   chalcopyrite (yellow) = black

3. Luster: the term luster refers to the general appearance of a mineral surface in reflected light. There are two types of luster; metallic and nonmetallic luster. If the mineral shows brilliant appearance as metal then, the luster is metallic luster. Minerals having metallic luster are generally opaque and reflect the light completely. e.g. galena, pyrite, chalcopyrite

   Minerals with a nonmetallic luster are, in general, light-colored and transmit light. The following terms are used to describe the nonmetallic luster.
   - Vitreous: the luster of glass e.g. quartz tourmaline
   - Resinous: having a luster of resin e.g. sulphur, sphalerite
   - Pearly: having a pearl like luster e.g. talc
   - Silky: the luster of silk e.g. gypsum, malachite
   - Admentine: the luster of diamond.
   - Earthy or dull: the luster of clay e.g. limonite

4. Transparency: this is the property of mineral that it allows to transmit light through it. A mineral is transparent when the outline of any object is seen through it, i.e. it

allows excess light to transmit through it. A mineral is translucent when light is transmitted through mineral but objects are not seen through it. When no light is transmitted through a mineral, it is said to be opaque.

5. Hardness: hardness is the resistant that the surfaces of mineral offer to scratching. It depends upon the bonding characteristics. A series of ten common minerals was chosen by Mohs (1824) as a scale, by comparison with which the relative hardness of a mineral can be told. The scale is known as Mohs scale of hardness.

    (a) Talc
    (b) Gypsum
    (c) Calcite
    (d) Fluorite
    (e) Apatite
    (f) Orthoclase
    (g) Quartz
    (h) Topaz
    (i) Corundum
    (j) Diamond

    Besides, the following things serves in addition to the above scale:
    Finger nail ~2, copper coin ~3, steel knife ~5, window glass ~5.5

6. Cleavage: cleavage is the tendency of minerals to break along certain definite planes. These cleavage planes are parallel to the weak atomic planes.
    (a) Cubic: 3 sets, e.g. galena
    (b) Rhombohedral: 3 sets, e.g. calcite
    (c) Octahedral: 4 sets, e.g. fluorite
    (d) Prismatic: 2 sets, e.g. barite
    (e) Basal: 1 set, e.g. Micas

7. Fracture: the term fracture is used when the way of breaking will not follow a particular direction. They break in all direction other than cleavage.
    (a) Concoidal fracture: breaks with curved concavities more or less deep and making half circles. E.g. quartz. If weak half circles are developed the term subconcoidal is used. e.g. bloodstone
    (b) Even: if the fracture surface is flattish.
    (c) Uneven or irregular: if the fracture surface is rough and irregular.
    (d) Hackly: jagged fractures with sharp edges. E.g. asbestos

8. Tenacity: the resistance that a mineral offers to breaking, crushing, bending or tearing is called tenacity.
    (a) Brittle: readily crushed to powder. e.g. calcite
    (b) Malleable: can be hammered out in to thin sheets e.g. metals
    (c) Sectile: can be cut in to thin shavings. e.g. graphite, gypsum
    (d) Ductile: can be drawn in to wire. e.g. metals flexible: the mineral or thin plate or lamina of it can be bent but doesn't return to its original position, e.g. talc
    (e) Elastic: after bending, the mineral springs back to its original position, e.g. micas

9. Specific gravity: ratio of weight of mineral to that of an equal volume of water.

10. Habit: the development of an individual crystal or an aggregate of crystal to produce a particular external shape.

Isolated crystals

(a) Acicular: needle like crystals, e.g. tourmaline
(b) Bladed: elongated crystal, flattened like knife blade, e.g. kyanite
(c) Foliated: consisting of thin and separate lamellae or plates, e.g. micas
(d) Prismatic: elongation of crystals in one direction, columnar crystals, e.g. amphibole

Crystal aggregates

(a) Botryoidal: spherical aggregation resembling a bunch of grapes, e.g. azurite
(b) Amygdaloidal: almond shaped aggregates, e.g. zeolite
(c) Dendritic: divergent branches, tree like crystal aggregates, e.g. native copper
(d) Radiating: arranged around a central point, e.g. aragonite
(e) Globular: forming small spherical groups, e.g. chromite
(f) Fibrous: consisting of fine thread like strands, e.g. asbestos

Mineral classification

Chemical composition is the bases for the classification of mineral classification. Minerals are divided into classes depending on the dominant anion or anionic group. Minerals having the same anion or anionic group dominant in their composition have unmistakable family resemblance, stronger and more clearly marked than those shared by minerals containing the same dominant cation.

The broadest divisions of the classifications are:

(a) Native elements
(b) Sulfides
(c) Sulfosalts
(d) Oxides
(e) Halides
(f) Carbonates
(g) Nitrates
(h) Borates
(i) Phosphates
(j) Sulfates
(k) Tungstates
(l) Silicates

Chemical composition of rock forming minerals

Although there are over 3000 minerals, only few are necessary to identify most rocks. Nearly 75% by weight of the earth's crust is oxygen and silicon. These two elements in combination with few other elements (Al, Fe, Ca, Na, K and Mg) account for the chemical composition of minerals that make up about 95% of the rocks of the earth's crust. Minerals that include the elements silicon and oxygen in their chemical composition are called silicates. Silicates are the most abundant rock forming minerals. The three most important rock forming silicate minerals or mineral groups are quartz, feldspar and Ferro-magnesian.

Quartz, one of the most abundant minerals, in the crust of the earth, is a hard, resistant mineral composed of silicon and oxygen. It is often white, but because of impurities it may be rose, purple, black etc. It is common mineral in river and most beach sands.
Feldspars, another important group of rock forming minerals, are alumino-silicates of potash, soda and lime. They are usually white, gray, or pink and, are fairly hard. feldspars are important commercial minerals.
Ferromagnesians are a group of silicates in which the silicon and oxygen combine with iron and magnesium. These are the dark colored minerals in most rocks. They are not resistance to weathering and erosion processes. Thus they tend to be altered relatively quickly to clay minerals.

Some important rock forming minerals are:

Quartz (SiO_2)
Quartz is one of the most widely distributed of all minerals: it forms an important part of many igneous rocks and is common in many sedimentary and metamorphic rocks. Quartz may occur in combination with other minerals or as in the case of pure sandstones and quartzite, may be the only one present. Pure quartz is composed of silica (SiO_2), the only oxide of silicon, but certain varieties contain impurities such as iron or manganese. These impurities are responsible for the varied colors of certain quartz.
Feldspars (Anorthite $CaAl_2Si_2O_8$, Albite $NaAlSi_3O_8$, Orthoclase $KalSi_3O_8$)
Minerals belonging to the feldspar group constitute the most important group of rock forming minerals. They are so abundant that they have been estimated to make up as 60% of the earth's crust. Feldspars are found in almost all igneous rocks as well as in many sedimentary and metamorphic rocks. Chemically, the feldspars are silicates of aluminum and one or two other metals. These may be K, Na, and Ca.
Mica
Minerals of the mica group are also, like feldspar, aluminum-silicates that are characterized by very complex chemical formulas. Micas are usually easily identified, as they typically occur in paper-thin, shiny, elastic cleavage plates. Only two varieties of micas, muscovite ($KAl_2[AlSi_3O_{10}][OH]_2$) and biotite ($K[Mg,Fe]_3[AlSi_3O_{10}][OH]_2$), are especially important as rock forming minerals. However phlogopite and lepidolite are fairly common in some rocks.

Muscovite, also known as white mica or potash mica, is usually transparent. It occurs typically in thin, elastic, scale like crystals, and is a common constituent of certain granites and pegmatites. It also occurs in certain metamorphic and sedimentary rocks. Biotite, or black mica, is very common mica and usually occurs in association with muscovite. It is found in many igneous and metamorphic rocks, where it is seen as thin, platy, shiny, black sheets. With the exception of the black color, the physical properties of biotite are essentially the same as those of muscovite.

Pyroxenes (XYZ_2O_6)

The pyroxene group is composed of complex silicates, and is among the most common of all rock forming minerals. The chemical composition of pyroxenes can be written as XYZ_2O_6 , where X= Na, Ca, Mn, Fe^{+2}, Mg, Li; Y= Mn,Fe^{+2}, Mg, Fe^{+3} and Z= Si, Al. this group of mineral are common constituent of many of the dark colored basic to ultra basic igneous rocks and also in certain types of metamorphic rocks.

Amphiboles

The amphiboles, another group of common rock forming minerals, are closely related to the pyroxenes. Because of their great similarity, these two groups are often confused. Chemically, they are complex silicates containing magnesium, calcium and iron. ***Hornblende*** ($[Ca,Na]_{2-3}[Mg,Fe,Al]_5Si_6[Si,Al]_2O_{22}[OH]_2$), the most abundant amphibole, is common constituent of igneous and metamorphic rocks.

Olivine ($[MgFe]_2\,SiO_4$)

Olivine is another group of rock forming minerals. The minerals are olive-green or brown in color. This is a common constituent of ultra basic igneous rocks.

Calcite ($CaCO_3$)

The mineral calcite is composed of calcium carbonate and is the most common member of the calcite group. It occurs in many sedimentary and metamorphic rocks, and is the primary constituent of most limestone and marble.

Dolomite ([CaMg] CO3)

A compound of calcium carbonate and magnesium carbonate, dolomite is common in sedimentary rock, where it is often mixed with calcite. It may also occur in association with many ore deposits and in veins or cavities in some igneous rocks.

Gypsum ($CaSO_4.2H_2O$)

Gypsum is a common mineral, is a hydrated form of calcium sulphate. A product of evaporation, it occurs in thick-bedded deposits, and is widely distributed in sedimentary rocks.

Clay minerals

The term clay is used for fine-grained, earthy materials that become plastic when mixed with a small amount of water. Compositionally, they are hydrous aluminum silicates, and are end product of weathering. Kaolinite ($Al_2SiO_5[OH]_4$), montomorillonite ($[Al,Mg]_8[Si_4O_{10}.12H_2O$), illite are important clay minerals.

Kyanite, Sillimanite, Andalusite (Al_2SiO_5)

The three polymorph (exists on different morphology with same composition) of Al_2SiO_5 are kyanite, sillimanite, and andalusites are found in metamorphic aluminous rocks. Kyanite (blue in color) is high pressure polymorph, sillimanite (brown to pale green in color) is high temperature polymorph, and andalusite (red, flesh colored) is moderate pressure and temperature polymorph.

Halite (NaCl)

Commonly called rock salt, halite is composed of sodium chloride. Large deposits of halite have been formed as a result of the evaporation of prehistoric inland seas in association with many other soluble salts and are laid down on the earth's crust in the form of sedimentary rocks. In many cases, another important common salt, the sylvite (KCl) is also found in association with the common rock salt, halite.

Serpentine ($Mg_3Si_2O_5[OH]_4$)

The serpentines are a complex group of hydrated magnesium silicates. They commonly occur in compact masses, which feel greasy or soapy. This is the alteration product of the olibine, pyroxene and amphibole. It is found in both igneous and metamorphic rocks.

Chlorite ($[Mg,Fe]_3[Si,Al]_4O_{10}[OH]_2[Mg,Fe]_3[OH]_6$)

The chlorite group is composed of complex silicates of aluminum, magnesium and iron, in combination with waters. These minerals are usually green in color and resemble the micas. These minerals generally occur in foliated or scaly masses. These are common constituents of many igneous and metamorphic rocks.

Apatite ($Ca_5[PO_4]_3[F,Cl,OH]$)

Apatite is the phosphatic group of minerals and found in many of igneous rocks, pegmatitic veins, sedimentary rocks and metamorphic rocks as well, but in very minor proportion as accessory mineral.

Nitratite ($NaNO_3$), Niter (KNO_3)

These are nitrate group of minerals and are found in association with the many other salts like calcite, halite, sylvite (KCl), but in minor proportions.

Significance of rock forming minerals:

The rocks having the ultra basic to basic composition of minerals like olivine, pyroxene, amphibole groups of minerals are highly susceptible to the weathering process, especially to chemical weathering process. These minerals readily break in to clay minerals and many other minerals, which are stable at the surface conditions. Thus, one can say, the rate of soil profile development on rocks those having ultra basic to basic minerals is faster than on those rocks which have the felsic composition of minerals like feldspar and quartz which are more stable in surface condition of the earth.

The three essential elements for promoting plant growth are potassium, nitrogen and phosphorus. Phosphatic rock is a valuable source of phosphorus because it contains a large amount of the mineral apatite. Sylvite is an important source of potassium, and natural nitrates are used in mineral fertilizers to provide nitrogen. Ground limestone (of whose chief component is calcite), gypsums etc. are also used in certain mineral fertilizers.

Principles of Stratigraphy

Stratigraphy also known as 'historical geology' is the study of the stratified rocks that aims at unraveling the geological history of the earth. Stratigraphy deals with the layered rock sequences of earth crust and also concerned with determining age relationship of layered rocks as well as their formation, distribution in space and time by reconstructing paleo-physical environment. Various principles or laws have been purposed as functional and scientific discipline of Stratigraphy. The most familiar, important basic principles are as follows:

1. Steno's principle of superposition: in any un-deformed and un-faulted sequence of layered rocks, every layer is formed after the layer below it and before the one above it. Each layer is younger than underlying layer and older than overlying layer. So this principle is very important tool for telling us the relative age of un-deformed strata. The main drawback of this principle is, it is not applicable for deformed and faulted area and fails in case of overturned strata.

2. Steno's law of lateral continuity: originally any single stratum or sedimentary layer probably was continuous through out its maximum aerial extent. This principle of lateral continuity doesn't imply that any layer or stratum ever continued indefinitely to cover the whole surface of the earth, but it must be limited to a given depositional basin.

3. Steno's principle of original horizontality: originally all the strata were deposited in horizontal layers wherever they are found in inclined position, generally horizontally but not exactly so. This principle of original horizontality can be reformulated as the concept that all sediments originally will be deposited at some angle less than their angle or repose.

4. Law of faunal succession: Smith noted that rock formed during the particular interval of time could be recognized by their characteristics fossil content. The older rock contains the more primitive remains and younger one contains the advanced life. But this principle is not always applicable because any primitive looking fossils are not necessarily older than any relative more advanced appearing fossils.

5. Law of facies: dealing with the succession of facies and lateral variation of deposition may takes place at the same time in different environment.

6. Law of uniformatarianism: this principle states that the past physical and the same process acting today pronounced biological features of the earth. This principle is given by James Hutton in late 1700s the uniformatarianism of process in the physical world is largely accepted but was not widely recognized as applicable in biological world until Charles Darwin (1859) convince with the scientific proof of biologic uniformatarianism called evolution for it.

7. Law of crosscutting relationship: interpretation of crosscutting relationship among the strata and emplaced roc bodies in prime importance in Stratigraphy. J. Hutton first clearly pointed out that any body of rock that crosses the boundaries of other units of rocks must be younger than those it cut.

8. Law of inclusion: J. Hutton formulated firstly this principle and this principle states the rock body contains fragments of another body of rock must be younger than the unit whose fragment it contains.

9. Law of correlation: equivalence or similar stratigraphic units can correlate with each other. Similarities may be expressed in paleontologic (fossil content0, lithologic (material based) or chronologic (time/age) evidence. Correlation is an essential element of most stratigraphic investigation.

Lithostratigraphic and chronostratigraphic units:

The new code of Stratigraphy recognizes four major categories of terms utilized by those geologists who studied layered or stratified rocks, the stratigraphers. These are the lithostratigraphic units, chronostratigraphic units, (geochronostratigraphic units and biostratigraphic units.)

The lithostratigraphic units or rock stratigraphic units, which are solely based in lithology (types and nature of material that forms the particular rock) for the division of the layered rock strata and having no necessary time relationship. The lithology of any particular rock has no time significance; it only signifies the one depositional environment and/or one type of event under which those sediments were accumulated to form the rocks. The similar lithology in different places signifies the same depositional environment and similar event that is related to the accumulation of that particular type of sediments.