Chapter - 4 Rock Forming Processes

Highlights :

- The two basic sources of energy called exogenic (driven by Sun) and endogenic (driven by geothermal energy within the Earth) are explained.
- Classification of rocks based on the mode of formation into three basic types (igneous, sedimentary and metamorphic) are elaborated.

Introduction :

As a terrestrial planet, Earth's interior is divided into the core, the mantle and the crust. The crust and upper mantle are collectively known as the lithosphere, from where the tectonic plates originate and plays an important role in governing the rock cycle which results in the formation of rocks.

The Earth has two basic sources of energy. The energy that reaches the Earth from the Sun (solar energy) is exogenic meaning from an external source. Solar energy is converted into heat and absorbed by the atmosphere, hydrosphere and lithosphere. This heat drives the water cycle which further controls the exogenic processes. The other source of energy arising within the Earth as geothermal energy is called endogenic. Large amount of heat is trapped within the Earth. This energy is responsible for endogenic processes like tectonic activity.

It is in the lithosphere where the rocks are formed, recycled and re-formed. The nature of these rocks differ depending on the processes by which they are formed. The origin of any rock can be determined by its texture and composition which in turn forms the basis of rock identification and classification. Study of rocks in terms of its composition, texture, structure, origin, occurrence, alteration and association with other rocks is called as Petrology. The word petrology is derived from the Greek word 'Petros' meaning rock and 'Logos' meaning science.

Rocks are naturally occurring aggregates of minerals. Based on their mode of formation, the rock forming processes are classified as :

i) Igneous processes that involve melting, cooling and crystallisation of magma or lava.

ii) Sedimentary processes involve weathering, erosion, deposition, and lithification of fragments of pre-existing rocks.

iii) Metamorphic processes involve changes in texture, structure and / or mineral composition under different temperatures and / or pressure conditions generally in presence of chemically active fluids.

Over geological time, rocks are gradually transformed from one type to another and the process is described as 'Rock Cycle'.

The rock cycle is a model that describes the formation, breakdown, and reformation of a rock as a result of sedimentary, igneous, and metamorphic rock forming processes.

4.1 Exogenic and endogenic processes :

The dictionary meaning of the term exogenic is the process originating at or near the surface of the Earth, such as weathering and denudation. The sedimentary rocks, ore deposits and landforms are commonly formed by the exogenic processes. Endogenic processes originate within the Earth giving rise to the rocks, ore deposits and landforms that form due to tectonism, diastrophism, volcanism and metamorphism.

4.2 Extraterrestrial processes :

These include landforms formed by extraterrestrial activity such as impact of meteorites, e.g. the Lonar lake (Buldhana district, Maharashtra).

4.3 Genesis, classification and characteristics of rocks :

The early Earth was like a ball of fire with everything in molten state. While cooling, the outermost solid surface (crust) was first formed and this rock is called as an igneous ('Ignis' meaning fire) rock. Thus, all the rocks formed due to rapid or slow cooling of magma (within the subsurface) and lava (on the surface of the Earth) are called igneous rocks. A large variety of igneous rocks are therefore classified on the basis of rate of cooling of magma / lava and depth of formation.

In due course of time, the Earth experienced rainfall initiating the hydrological cycle (water cycle). This in turn initiated the phenomenon of weathering and denudation resulting in erosion and transportation of pre-existing rocks and their deposition in basins. Consolidation of the deposited material formed sedimentary rocks ('sedimentum' meaning settling). Several geological processes can result in rise in temperature and pressure causing the recrystallization of minerals of pre-existing rocks. These newly developed rocks are called as metamorphic (meta meaning 'After', morphic meaning 'Change in form') rocks.

The different approaches to the study of rocks are petrography, petrology, petrogenesis and lithology.

Petrology is a branch of geology that deals with description and systematic classification of rocks. The study of rocks as thin sections under microscope is called petrography.

Petrogenesis is a branch of petrology that deals with the origin and formation of rocks.

Lithology is a general terminology for description of rocks in hand specimen/or in the field, using characteristics like colour, texture and mineral composition.

4.3.1 Genesis, classification and characteristics of igneous rocks :

Igneous rocks are formed by cooling and consolidation of hot, molten rock material.

Magma :

Magma is a hot molten material formed at great depth. The temperature of the magma is around 800° to 1400° C. It is a hot melt of rocks or minerals. It is under great pressure at depth. Any factor which reduces the pressure will cause the eruption of the magma. Magma consists of volatile (gaseous) substances such as, water vapour, carbon dioxide, sulphur dioxide, etc. and non-volatile substances like oxides of silicon, aluminium, iron, calcium, sodium, potassium, magnesium, etc. When the same hot molten rock material erupts on the surface, it is known as lava.

Formation of igneous rocks :

When the magma present at great depth moves upward into the Earth's crust, both pressure and temperature decreases. Decrease in pressure within the crust will cause the intrusion of the magma onto the surface, as lava. Reduction of pressure allows the gases to escape into the surrounding rocks of the crust. The magma cools slowly and the whole mass of different minerals gives rise to igneous rocks. Types of igneous rocks thus formed, depends upon the original composition of the magma and its rate of cooling. Under slow rate of cooling, there is sufficient time and space for igneous rocks to form larger crystals (e.g. gabbro) whereas if the rate of cooling is rapid, fine grained rocks are formed. If the cooling is very fast, the rock melt does not develop minerals and forms a glassy rock, e.g. pitchstone, obsidian.

The igneous rocks, which are formed inside the Earth by injection of magma are known as intrusive or hypabyssal igneous rocks. These rocks are formed under a slow rate of cooling, are relatively medium grained. e.g. dolerite.

The rocks which are formed on the surface

by the eruption of volcanoes are known as extrusive or volcanic igneous rocks. These rocks are formed under conditions of rapid rate of cooling, are fine grained. e.g. basalt.

Classification of igneous rocks :

Igneous rocks are classified on the basis of genesis, chemical and mineralogical composition, petrographic characters and occurrences.

A simple classification is suggested based on chemical, mineral and textural characters. The chemical classification considers magmatic composition in which the percentage of felsic minerals (silica and aluminum bearing) and mafic minerals (iron and magnesium bearing) are present. Accordingly, the rocks having SiO_2 % > 66% are termed as acidic, those containing SiO_2% : 65% - 55% are called intermediate, rocks containing SiO_2% : 54% - 44% are basic while rocks with SiO_2% < 44% are termed ultrabasic (Table 4.1).

Quartz is a mineral entirely comprising of SiO_2, whereas SiO_2 can also occur in rocks as silicate compounds with other elements.

Classification based on mineral composition considers essential and accessory minerals, such as felsic and mafic rocks. Felsic rocks are light in color consisting of feldspars and quartz. Mafic rocks are dark colored, consisting of olivine, pyroxenes and amphiboles.

The general classification suggested for beginners is based on :

1) Mode of occurence or depth of formation.
2) Percentage of quartz or silica
3) Presence of feldspars.

On this basis igneous rocks are classified as plutonic, hypabyssal and volcanic.

Plutonic igneous rocks :

Plutonic ('Pluto' meaning god of underworld) describes the igneous rock material whose origin is deep seated. Rate of cooling at this depth is slow. As a result, large and almost equal sized crystals are formed. Texture thus formed is called equigranular. The matrix of such rocks is completely composed of crystals which can be recognized by unaided eye. Such rocks are termed as holocrystalline ('holo' meaning complete) e.g. granite, syenite, gabbro.

Volcanic igneous rocks :

Magma generated within a magmatic chamber is suddenly and rapidly pushed upwards to the surface due to tectonic activity. As the magma moves upwards, fine grained minerals are formed due to rapid cooling. Before and during this movement, the earlier formed minerals grow larger in size. The admixture of fine and coarse grained minerals thus formed is described as porphyritic texture. Very rapid cooling does not permit crystallization, resulting into glassy (holohyalline) rock e.g. rhyolite, trachyte and basalt.

Table 4.1 : Tabular classification of igneous rocks

Silica %	Mode of occurence or depth of formation		
	Plutonic	**Hypabyssal**	**Volcanic**
Acidic (> 66%)	Granite	Pegmatite	Rhyolite
Intermediate (65 - 55%)	Syenite		
Basic (54 - 44%)	Gabbro	Dolerite	Basalt
Ultrabasic (< 44%)	Dunite		

Hypabyssal igneous rocks :

The term hypabyssal is used for intrusive igneous rocks that crystallize at intermediate depths i.e., between plutonic and volcanic conditions. Some hypabyssal rocks contain coarse as well as fine grained minerals showing porphyritic relationship (e.g., pegmatite, dolerite).

Characteristics of igneous rocks :

1) These are first formed rocks by the cooling of magma or lava, hence are also called as primary rocks.
2) They are massive and unstratified.
3) They are non-fossiliferous.
4) They often occur as veins and fissures intruding into country rocks.
5) They exhibit baking or alteration effects along their contacts with country rocks.
6) They display an interlocking texture consisting of minerals, glass or both.
7) Lava flows may show gas cavities or amygdales.
8) They are composed of pyrogenetic minerals formed at high temperature.
9) They exhibit equigranular / porphyritic / glassy texture.

4.3.2 Genesis, classification and characteristics of sedimentary rocks :

Sedimentary rocks are formed by weathering and erosion of the pre-existing rocks. The process of weathering and erosion is carried out by agents like sunlight, river, wind, glaciers, and oceans. The eroded products are transported and later deposited. These loose sediments on consolidation give rise to sedimentary rocks.

Genesis :

Sedimentary rocks are formed by lithification of weathered rock fragments that are physically transported and deposited. During transportation the fragments are abraded resulting in reduction in size. Such fragments are called clasts and the rock is referred to as clastic e.g., conglomerate and sandstone. Some of these rocks are formed from chemical precipitation and crystallisation. Such rocks are termed as non-clastic e.g., limestone. Few sedimentary rocks are also formed by lithification of organic matter like shell fragments and are called as bioclastic e.g., fossiliferous limestone.

The process of deposition of loose fragments or clasts or rock debris is termed as sedimentation. It also includes material precipitated from solutions or water.

Classification :

Sedimentary rocks can be classified based on type of weathering, transportation and grain size (Table 4.2)

During transportation, water reacts with minerals and may form solutions. Under appropriate conditions precipitation takes place leading to formation of two types of deposits :

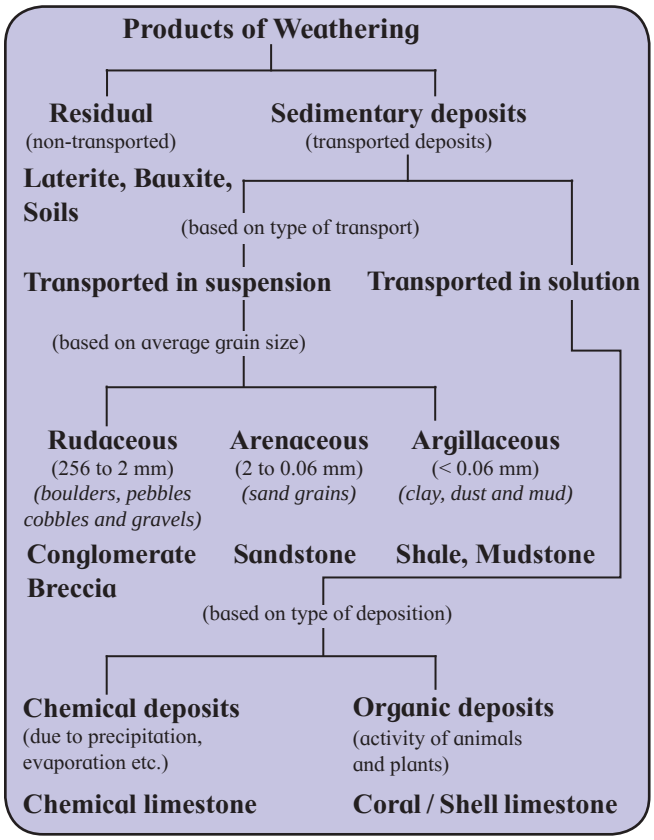
1) Chemical deposits : These deposits are formed by evaporation and precipitation e.g., limestone.
2) Organic deposits : Fragments of shells of animals and parts of plants are deposited and cemented to form fossiliferous and shell limestone.

During weathering, a rock may undergo *in-situ* chemical changes giving rise to residual deposits e.g., laterite, bauxite and soil.

Characteristics of sedimentary rocks :

1) They are derived from mechanical and / or chemical breakdown of pre-existing rocks.
2) Most of these rocks are layered or stratified.
3) These rocks show clastic textures with different cementing materials like silica, calcium carbonate, iron oxide, carbon or clay.
4) These rocks may contain fossils.
5) They may show primary structures like current bedding, ripple marks and mud cracks.
6) They may contain tracks, trails, burrows and imprints.

Table : 4.2 Classification of sedimentary rocks



4.3.3 Genesis, classification and characteristics of metamorphic rocks :

Rocks may undergo transformation due to change in temperature, pressure and presence of chemically active fluids.

Almost all pre-existing rocks are subjected to heat and pressure below the surface of the Earth. This brings about change in mineral composition and texture of original rock by recrystallisation. This results in the formation of new rock termed as metamorphic rock. Thus, the resulting rock shows change in mineral composition, texture and structure.

Genesis :

Metamorphism results from the change in physical and chemical environment of the original rock. These changes are because of different factors known as agents of metamorphism which are : temperature, pressure and chemically active fluids and gases.

1) **Temperature :** This is the most important agent of metamorphism. A rock begins to change chemically at temperatures above 200°C. Temperature increases with increasing depth (due to geothermal gradient), intrusion of magma, plate tectonics and radioactive decay.

2) **Pressure :** Pressure increases with depth and due to tectonic movements. Rocks can be subjected to pressures of two kinds:

a) Directional pressure

b) Uniform or hydrostatic pressure.

Directional pressure is dominant within tectonically active zones. It is also termed as non-uniform pressure or stress. The effect of stress reduces the melting point of minerals and increases their solubility. As depth increases the directional pressure gradually changes into confining or uniform pressure.

3) **Chemically active fluids and gases :** These are derived from magma and are called as hydrothermal solutions. These fluids may contain carbon-dioxide, hydrofluoric acid, bromine, fluorine and water vapour in supersaturated state.

Classification of metamorphic rocks :

Metamorphic rocks are classified into three categories based on agents of metamorphism.

1) **Cataclastic metamorphism :** In this type the directional pressure plays an important role. There is no significant change in temperature. Since, directional pressure is the only operating agent, it mechanically breaks down the rock by crushing, fracturing and granulation. In this process no new mineral is formed e.g., slate.

2) **Thermal metamorphism :** In this kind of metamorphism there is increase in temperature, which is the dominant factor. The main source of heat is intrusion of magma. Along the contact between magma and host rock, recrystallization takes place (e.g., sandstone metamorphosed to quartzite and limestome metamorphosed to marble).

Table 4.3 : Genesis of metamorphic rocks

Original Rock	Types of Metamorphism (agent of metamorphism)	Product of Metamorphism	Structure
Argillaceous	Cataclastic (directed pressure or stress)	Slate	Slaty cleavage
Sandstone / Limestone	Thermal (temperature)	Quartzite/Marble	Granulose
Argillaceous (shale, mudstone) Basic igneous rock (basalt, gabbro)	Dynamothermal (directed pressure and temperature dominant)	Mica-garnet schist, Biotite schist, Biotite gneiss. Hornblende schist, Hornblende gneiss.	Schistose and Gneissose

3) **Dynamothermal metamorphism :** This metamorphism is also called regional metamorphism. Here heat and directional pressure are dominant. The rise in temperature and directional pressure is due to tectonic activity or magmatic intrusion. The temperature recrystallises the pre-existing minerals and directional pressure aligns the minerals perpendicular to direction of maximum pressure, thereby orienting the minerals to form schists and gneisses, e.g., hornblende gneiss, mica-garnet schist.

Characteristics of metamorphic rocks :

1) Metamorphic rocks are derived by the physical and chemical transformation of pre-existing (igneous, sedimentary or metamorphic) rocks.
2) They are formed in response to pronounced changes in the temperature, pressure and chemical environment.
3) Mineral transformation takes place in the solid state.
4) These rocks exhibit recrystallisation.
5) Metamorphic rocks show interlocking arrangement of minerals.
6) They exhibit granularity, schistosity and gneissosity.
7) Staurolite, kyanite, sillimanite, garnet are characteristic metamorphic minerals.
8) Metamorphic rocks are devoid of fossils but are favoured to form economic ores and gemstones.

4.4 The rock cycle :

The rock cycle explains the evolution and transfer of igneous, sedimentary and metamorphic rocks. Rock components of the crust, slowly but consistently, are being changed due to different processes operating on the Earth.

The rock cycle is driven by two forces :

1) Earth's internal heat responsible for the endogenic processes.
2) The hydrological and other cycles on the Earth's surface powered by the sun (exogenic processes).

Due to internal forces generated within the Earth the intrusive rocks are uplifted and exposed to the surface. On their exposure to the atmosphere, these rocks get weathered, both physically and chemically. The weathered material after erosion gets transported by different agents and finally gets deposited as unconsolidated sediments along rivers, lakes and the ocean. With further addition of sediments, the weight (overburden) increases and the layers begin to subside. Eventually, with depth, the sediments are heated and partially melted to get mixed with the mantle material. This mixed mantle material may once again erupt as igneous rocks. Pre-existing rocks can be subjected to temperature and pressure and change to form metamorphic rocks. Thus, in nature, there appears to be a cyclic production, destruction and reproduction of all the three types of rocks. This appears to be a continuous process, ever since the

process of weathering and erosion started. This phenomenon is called the Rock cycle (Fig. 4.1)

Activity :

Collect various types of rocks from your area of residence and also from rock polishing shops. Identify their mineral contents and sort the rock samples into igneous, sedimentary and metamorphic rocks.

Summary :

The rocks are transformed from one type to another in response to the endogenic and exogenic processes by altering their mineralogy, texture and other physico-chemical properties.

Rocks are classified into three basic types and their intermediate forms are explained by the rock forming processes.

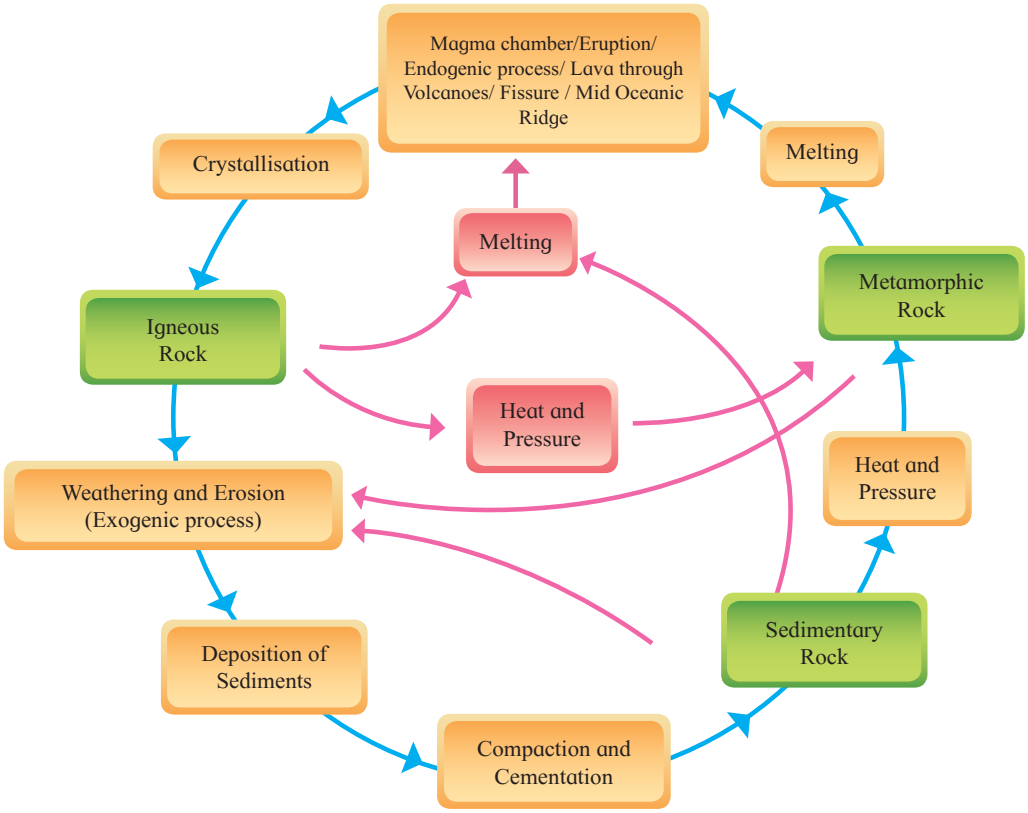


Fig. 4.1 : Rock cycle

EXERCISE

Q. 1. Fill in the blanks :

1) Metamorphic rocks characteristically show ..... of material.

2) Cycle driven by exogenous and endogenous processes is known as .....

Q. 2. Multiple choice questions :

1) Sedimentary rocks are mainly formed by..... processes.

a) endogenous b) exogenous

c) extra terrestrial

d) both exogenous and exogenous

2) If no crystallization takes place ..... rock is developed.

a) holocrystalline b) glassy

c) plutonic d) Hypabyssal

Q. 3. Give geological terms :

1) Rocks that are classified on the basis of grain size are .....

2) The class of igneous rocks which exhibit equigranular textures are .....

Q. 4. Match the pairs :

1)

Process	**Product**
A) Cataclastic	i) Granite
B) Thermal	ii) Slate
C) Dynamothermal	iii) Quartzite
D) Plutonic	iv) Mica Schist

1) A-ii, B-iii, C-iv, D- i
2) A-iii, B-ii, C-i, D-iv
3) A-iv, B-i, C-iii, D-ii
4) A-ii, B-iv, C- iii, D- i

2)

Types	**Rocks**
a) Rudaceous	i) Shell limestone
b) Organic deposits	ii) Conglomerate
c) Argillaceous	iii) Limestone
d) Chemical deposits	iv) Mudstone

1) a-ii, b-ii, c-iv, d-iii
2) a-i, b-ii, c-iii, d-iv
3) a-iii, b-iv, c-ii, d-i
4) a-ii, b-i, c-iv, d-iii

Q. 5. Strike the odd one out :

1) Plutonic, Hypabyssal, Volcanic, Organic deposits.
2) Rudaceous, Arenaceous, Argillaceous, Hypabyssal
3) Cataclastic, Thermal, Dynamothermal, Volcanic.

Q. 6. Eliminate the incorrect statement :

1) The crystallisation of magma is not governed by the ..... .
   a) Temperature and pressure
   b) Composition of magma
   c) Visco sity of magma
   d) Geographic position of the magma on the Earth's surface
2) Plutonic igneous rocks are ..... .
   a) Deep seated and have moderate temperature pressure conditions.
   b) Near the Earth's surface and possess high temperature pressure conditions.
   c) Deep seated with high temperature pressure and fast cooling conditions.
   d) Deep seated along with high temperature pressure and slow cooling conditions.

Q. 7. Distinguish between :

1) Igneous and Metamorphic
2) Volcanic Igneous and Plutonic Igneous
3) Rudaceous and Arenaceous
4) Cataclastic and Thermal metamorphism.

Q. 8. State whether True or False and justify in either case :

1) Hypabyssal rock contain coarse and fine grained minerals.
2) Sedimentary rocks are layered or stratified
3) Metamorphic rocks are exhibit recrystallization.

Q. 9. Write short notes on :

1) Characteristics of igneous rocks
2) Classification of sedimentary rock
3) Genesis of sedimentary rocks
4) Genesis of metamorphic rocks

Q. 10. Give geological reasons :

1) Plutonic igneous rocks usually exhibit coarse grained texture.
2) Volcanic rocks exhibit fine grained texture.
3) No new minerals are formed in cataclastic metamorphism.
4) Some minerals are formed in dynamothermal metamorphism.

Q. 11. Answer in detail :

1) Explain the process of transformation of igneous and metamorphic rocks to sedimentary rocks.
2) Explain the role of endogenic and exogenic process in conversion of one rock type into another.
3) Explain how metamorphic rocks can be converted to sedimentary rocks.