# The Rocks

## Introduction:

The rocks from a major part of the earth's crust. They may be defined as aggregates of minerals. Some rocks, such as quartzite (quartz) and marble (calcite), contain grains of one mineral only but most are composed of a variety of different minerals. The rocks are broadly classified into three groups: (1) igneous, (2) sedimentary, and (3) metamorphic.

Igneous rocks are formed by cooling and solidification of magma. Typical igneous rocks are granite and basalt.

Sedimentary rocks are formed by consolidation and cementation of the sediments deposited under water. Typical sedimentary rocks are sandstone, limestone and shale.

Metamorphic rocks are formed when the pre-existing rocks have been changed in texture and composition by increased temperature and pressure. Typical rocks of this kind are schist and gneiss.

## Igneous Rocks:

Approximately 90% of the earth's crust is composed of igneous rocksbut their great abundance is hidden on the earth's surface by a relatively thinlayer of sedimentary and metamorphic rocks. "Igneous rocks" are formedby cooling and solidification of magma. 'Magma' is a hot viscous, siliceousmelt containing water vapor and gases. It comes from great depth belowthe earth's surface. It is composed mainly of O, Si, Al, Fe, Ca, Mg, Na and K. When magma comes out upon the earth's surface, it loses its gases.Such magma is called "lava".

## Occurrence of Igneous Rocks:

Magma is produced deep in the earth's crust where temperatures are of the order of $900^{o}$-$1600^{o}C$. It being lighter than the surrounding rocks, works its way towards the surface. On consolidation it produces two major types of igneous rocks:

(1) Extrusive.
(2) Intrusive.

## Extrusive Rocks:

When magma reaches the earth's surface, it causes a volcanic eruption. This eruption generates extensive Iavaflows. The rocks formed due to solidification of lava are called "extrusive rocks". The extrusive rocks are also called the "volcanic rocks". As are generally fine grained or glassy. During cooling of lava, the volatiles present in it escape into the atmosphere. Volcanic rocks often contain gas cavities, called the "vesicles". These rocks sometimes show "flow structure" which is the result of movement in a viscous lava. It is seen as lines or streaks of different colour in a rock.

## Intrusive Rocks:

Intrusive rocks are formed when magma crystallizes beneath the earth's surface. Depending on the depth of formation, intrusive rocks are divided into two groups: (1) plutonic rocks, and (2) hypabyssal rocks.

Plutonic Rocks - Rocks crystallized at great depths are called "plutonic rocks". A magma which is deeply buried in the earth's crust.Cools slowly with the retention of the volatiles. As a result the mineral constituents crystallizing from it have time to grow to considerable size giving the rock a coarse grained texture.

Hypabyssal Rocks-hypabyssal rocks are formed when magma solidifies close to the earth's surface. These rocks occur as injections within the country rocks. Their textures are usually finer grained than those of plutonic rocks but coarser than those of volcanic rocks. The hypabyssal rocks commonly show porphyritic texture.

## Classification of igneous rocks:

Igneous rocks are classifiedto:

A.Depend upon composition of the magma from which they are originated. Magmas are divided into two broad groups:

(1) acid magma.

(2) basic magma.

The "acid magma" is rich in Si, Na and K, and poor in Ca, Mg and Fe. The "basic magma" on the other hand, is rich in Ca, Mg and Fe, and poor in Si, Na and K.

B.Depend upon silica percentage, igneous rocks are classified into the following groups.

(1) Ultrabasic Rocks. These contain less than 45% silica, e.g. peridotite.

(2) Basic Rocks. These contain silica between 45% and, 55%, e.g. gabbro and basalt.

(3) Intermediate Rocks. These contain silica between 55% and 65%, e.g. diorite.

(4) Acid Rocks. These contain more than 65% silica, e.g. granite.

In general, acid igneous rocks are light in colour, low in specific gravity (about 2.7) and have high proportion of minerals like quartz and alkali felspars. Acid rocks are also called the "felsic rocks". An example of acid rock is granite. Basic rocks, on the other hand, are usually dark in colour (often black), relatively high in specific gravity (about 3.2) and contain mainly silica poor minerals, such as olivine, pyroxene, hornblende or biotite and little or no quartz. Basic rocks are also called "mafic rocks" as they contain a high percentage of ferromagnesian minerals. An example of basic rock is basalt.

(1) oversaturated rocks.
(2) saturated rocks.
(3) undersaturated rocks.

(1) Oversaturated Rocks. These rocks crystallize from melts containing higher amount of silica. They contain abundant quartz and alkali feldspars.

(2) Saturated Rocks. These rocks are formed when the amount of silica present in the melt is just sufficient to form silicate minerals. saturated igneous rocks do not contain quartz.

(3) Undersaturated Rocks. These rocks crystallize from a melt which is deficient in silica and high in alkalies and aluminium oxide. Such rocks contain silica poor minerals, such as felspathoids, and lack quartz.

Many schemes have been proposed for the classification of igneous rocks but the most useful for the beginners is based on mineralogy and texture. In this scheme the various criteria that are considered in classifying igneous rocks are as follows:

(1) Relative Silica content. presence of quartz in an igneous rockindicates excess of silica whereas felspathoids indicate deficiencyof it.
(2) Kinds of Felspar. Determination of relative amount of alkalifelspar and plagioclase helps greatly in classifying igneous rocks.
(3) Mafic Minerals. The relative amount and type of mafic mineralspresent in an igneous rock are determined. This information isvaluable from the point of view of classification of igneous rocks.
(4) Texture. Texture of an igneous rock is an important criterion of classification.

The classification of igneous rocks based on their mineralcomposition and texture is given in Table 4.

**Table4**: Classification of Igneous Rocks

| Composition | Mainly Alkali feldspar | Alkali feldspar = Plagioclase | Mainly Plagioclase |
|---|---|---|---|
| ACID<br>(Light Minerals > 60%) | GRANITE<br>Rhyolite | ADAMELLITE<br>Rhyodacite | GRANODIORITE<br>Dacite |
| INTERMEDIATE<br>(Light minerals 60-30%. Quartz <1O%) | SYENITE<br>Trachyte | MONZONITE<br>Trachyandesite | DIORITE<br>Andesite |
| BASIC<br>(Dark minerals > 6o%. Clacite-plagioclase | ALKALI-GABBRO<br>Alkali-basalt | SYENO-GABBRO<br>Trachybasalt | GABBRO<br>Basalt, Dolerite |
| ULTRABASIC<br>(No feldspar) | | | DUNITE<br>PERIDOTII'E<br>PYROXENITE |

(PLUTONIC rocks in capitals, Volcanic rocks in small letters)

Quartz is an essential mineral in acid rocks. It occurs as anaccessory mineral in intermediate and basic rocks while it remains absent in ultrabasic rocks. Potash felspars together with sodium rich plagioclases are known as the "alkali felspars". Alkali felspars occur as essentialminerals in acid rocks but they are either absent or found in only in minor amounts in intermediate, basic and ultrabasic rocks. Calcium rich plagioclases are found mostly in basic rocks and andesine in intermediate rocks. ultrabasic rocks normally do not contain felspares.

Olivine occurs as an essential mineral only in basic and ultrabasic rocks.pyroxenes and amphiboles are the important constituents of basic and ultrabasic rocks but they occur as accessory minerals in acid and intermediate rocks.

## Textures:

Textures means the size, shape and arrangement of mineral grains in a rock. The grain size of an igneous rock depends on the rate of cooling of magma. In the study of texture four points are considered. These points are:

(1) degree of crystallization.

(2) size of grains.

(3) shape of crystals.

(4) mutual relation between mineral grains.

## Degree of Crystallization:

On the basis of degree of crystallization, textures of igneous rocks can be divided into the following groups.

(1) Holocrystalline Texture. When a rock is made up entirely of crystals, its texture is described as "holocrystalline"(Figure 8 a).

(2) Holohyaline Texture. When a rock is composed entirely of glassy material, its texture is called "holohyaline"(Figure 8 b).

(3) Merocrystalline Texture. When a rock is composed partly of crystals and partly of glass, the texture is called "merocrystalline"(Figure 8 c).".

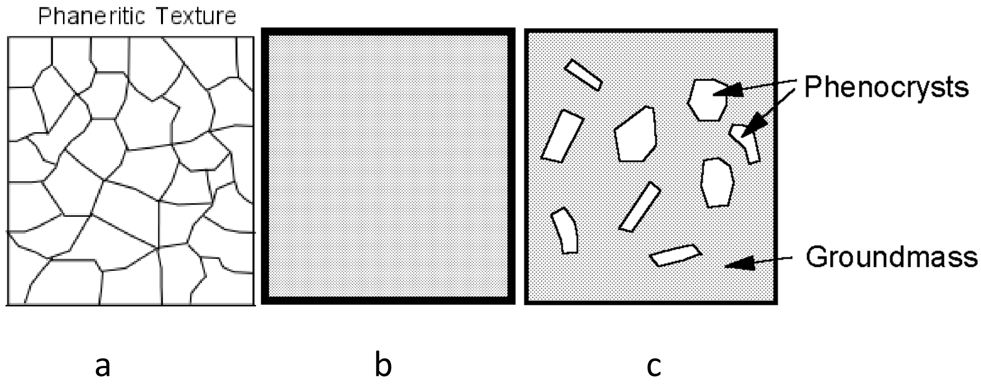



**Figure 8:**aHolocrystalline, b Holohayaline,c Merocrystalline

## Size of Grains:

The size of grains in an igneous rock varies considerably. The slow cooling gives crystals time to grow to sizes greater than 5 mm. in rapid cooling, the mineral grains crystallize quickly as a mass of tiny crystals which are generally less than one millimeter in size. In some lavas, the cooling is so rapid that they fail to crystallize and "glassy texture" results.

Igneous rocks whose constituent mineral grains can be seen with the naked eyes, are described as "phaneric".

A .Phaneric (Coarse grains, medium grains, small grains).

while those whose mineral grains are too small to be seen with the naked eyes, are called "aphanitic".

B. Aphanitic (Microcrystalline, cryptocrysalline.

*Coarse grained texture(grain size more than 5mm).

* Medium grained texture( grain size from 1mm to 5mm).

* Fine Grained Texture(The grains are like granulated sugar where their diameter is less than one millimeter.

Most Intrusive igneous rocks are coase grained.

Most extrusive igneous rocks are fine grained.

C.MicrocrystallineTexture".In an aphanitic rock if the mineral grains can be distinguished under a microscope, the rock is said to be " microcrystalline".

D. Cryptocrystalline Texture. In a cryptocrystalline texture, thindividual crystals are very small. They are not visible under themicroscope but their presence can be felt as they react to the polarized light.

## Shape of Crystals:

The grains of an igneous rock are called. "euhedral" if they show well developed crystal faces, and if the crystal faces are partly developed, they are described as "subhedral". The term "anhedral" is used for those grains in which crystal face are absent.

## Mutual Relations of Grains:

Depending on mutual relations of grains, the textures of igneous rocks may be classified into four major groups : (1) equigranulartexture, (2)inequigranulartexture, (3) directive texture, and (4) intergrowth texture.

Equigranular Texture. Igneous rocks containing mineral grains of more or less equal size are said to have an "equigranular texture".Equigranular textures are of the following types.

(1) PanidiomorphicTexture. Whenmost of the grains areeuhedral, the texture of rock is called "panidiomorphic ". This texture is usually found in lamprophyres.

(2) HypidiomorphicTexture. When most of the crystals aresubhedral, the texture is called "hypidiomorphic". This texture is characteristic of many plutonic rocks such as granites and syenites.

(3) Allotriomorphic Texture. When most of the crystals are anhedral, the texture is called "allotriomorplric". This texture is found in some aplites.

(4) Microgranular Texture. Microcrystalline igneous rocks may also have an equigranular texture. The crystals of these fine grained rocks are

commonly anhedral or subhedral. Such a texture is called "mircrogranular texture".

(5) Orthophyric Texture. Some highly felspathic rocks such as orthophyres and plagiophyers, possess a fine grained panidiomorphic texture. This texture is called "orthophyric texture".

(6) Felsitic Texture. An igneous rock containing a uniform mass of cryptocrystalline matter is said to have a "felsitic texture".

Inequigranular Textures. Igneous rocks showing variations in the size of mineral grains are said to have the "inequigranular texture".Inequigranular textures are of the following types.

(1) Porphyritic Texture. When an igneous rock contains largecrystals of some minerals set in a matrix which is much finergrained or even glassy, the texture is called "porphyritic. The large crystals are called "plzenocrysts" and thefiner grained material is called "groundmass".Igneous rocksshowing porphyritic texture are known as "porphyries" suchas granite porphyry diorite porphyry and rhyolite porphyry.This texture develops when some of the crystals grow to aconsiderable size before the main mass of the magma consolidatesinto finer and uniform grade material.

(2) Poikilitic Texture. when in a rock smaller crystals are enclosed within larger crystals without common orientation, the texture is called "poikilitic texture". This texture is commonly found in syenites and monzonites where orthoclase forms the host mineral.

(3) Ophitic Texture. "Ophitic texture" is a special type of "poikiliticthexture in which bigger crystals of augiteenclosesmaller laths ofplagioclase. If the plagioclase laths are onlypartly enclosed in the larger grains of augite, the texture iscalled "sab-ophitic". Ophitic texture is characteristicofdolerites.

(4) Intergranular and Intersertaltextures. In manybasaltsplagioclase laths occur in such a way that they form a networkwith triangular or polygonal interspaces. These interspaces arefilled with minute grains of augite, olivine and iron oxide.Such a texture is called

"intergranulartexture". When glassyor fine grained chloritic or serpentinous materials occur in thinnerspaces, the texture is called "intersertal".

Directive Textures. The textures produced as a result of flow of lavasduring theirconsolidation, are called "directive textures',. The chief directivetextures are as follows.

(1) Trachytic Texture. Certain volcanic rocks, such as trachyte,contain felspar laths arranged inlines parallel to the direction of

flow of lava. Such a texture iscalled the "trachytic texture.

(2) Hyalopilitic Texture. In a volcanicrock iffelspar laths arefound intermixed with glass, thetexture is called "hyalopilitic".

## FORMS OF IGNEOUS BODIES:

**Batholith**:Batholithsare large intrusive igneous bodies which have transgressive relation with the adjacent country rocks. Their diameter is usually 100 km or more and their outcrop at the surface is roughly circular or oval. In cross-section batholiths possess steep outwardly dipping contacts and they are thought to bebottomless. The composition of batholiths is usually granitic orgranodioritic.

**Stock and Boss**:Irregular igneous masses of batholithic habit are called''stocks". They are of smaller size and their diameter is usually between l0to 20 kilometers. The term "boss" isapplied to those stocks whichhave an approximately circular outcrop.

**Lopolith**: A "lapolith" is a saucer shaped concordant igneous body

which is bentdownward into a basin like shape . Its diameter isusually 10 to 20 times its thickness. Thus lapoliths are very much largerthan laccoliths The composition of lapoliths is commonly basic.

**Laccolith**: A "laccolith" is a lens shaped intrusive igneous body which causes the overlying beds to arch in the form of a dome .It has aflat base and e. domed top. Alaccolith may be 2 to 3 kilometers in diameterand several hundred meters in thickness. Itdiffers from a batholith in being much smaller and having a knorvn floor.

**Phacolith**:"Phacolith" are crescent shaped bodies of igneous rocks.They occupy crests and troughs of folded strata,Phacolithareformed when igneous material invades the foldedregion. The igneous material accumulates at the crests and troughs of folds because these are thezones of minimum stress.

**Sill**: A "sill" is a sheet like igneous body which runs parallel to the bedding planes o1'the pre-existing strata. They may be horizontal, inclined or vertical depending upon the attitude of strata in which they are intruded. Sillsvary in thickness from a few centimeters to several hundred meters but they are always thin as compared to their length along beds. Sillsare commonly made up of dolerites and basalts.

**Dyke**: A "dyke" is a wall like igneous body that cuts across the strata of the pre-exsiting rocks. Dykes are often vertical or steeply inclined. Their thickness varies from a few centimeters to a hundred meter or more. Dykes tend to occur in groups where they run parallel to one direction or are radial to a centre. A dyke having a circular outcrop and a conical form is called a "ring dyke". Those which have inverted conical form and circular outcrops are described as "cone-sheets". Dykes probably represent a crustal fracture into which the magma was injected.

**Volcanic Plug**: A volcanic plug is a vertical cylindrically shaped igneous body which has a roughly oval or circular cross-section . It represents the vent of an extinct volcano. Volcanic plugs range in diameter from a few hundred meters to a kilometer or more.

**Lavaflows**: The volcanic igneous rocks occur as lavaflows. The lavaflows are tabular in shape and may range in thickness from afew meters to several hundred meters. They are formed when lava erupts on the earth's surface from fissures. The lavas cover a very large area before solidifying and considerable thickness of rock is formed from repeated eruptions. The Deccan Traps which cover a vast area in Central India, is a famous example of lavaflows.

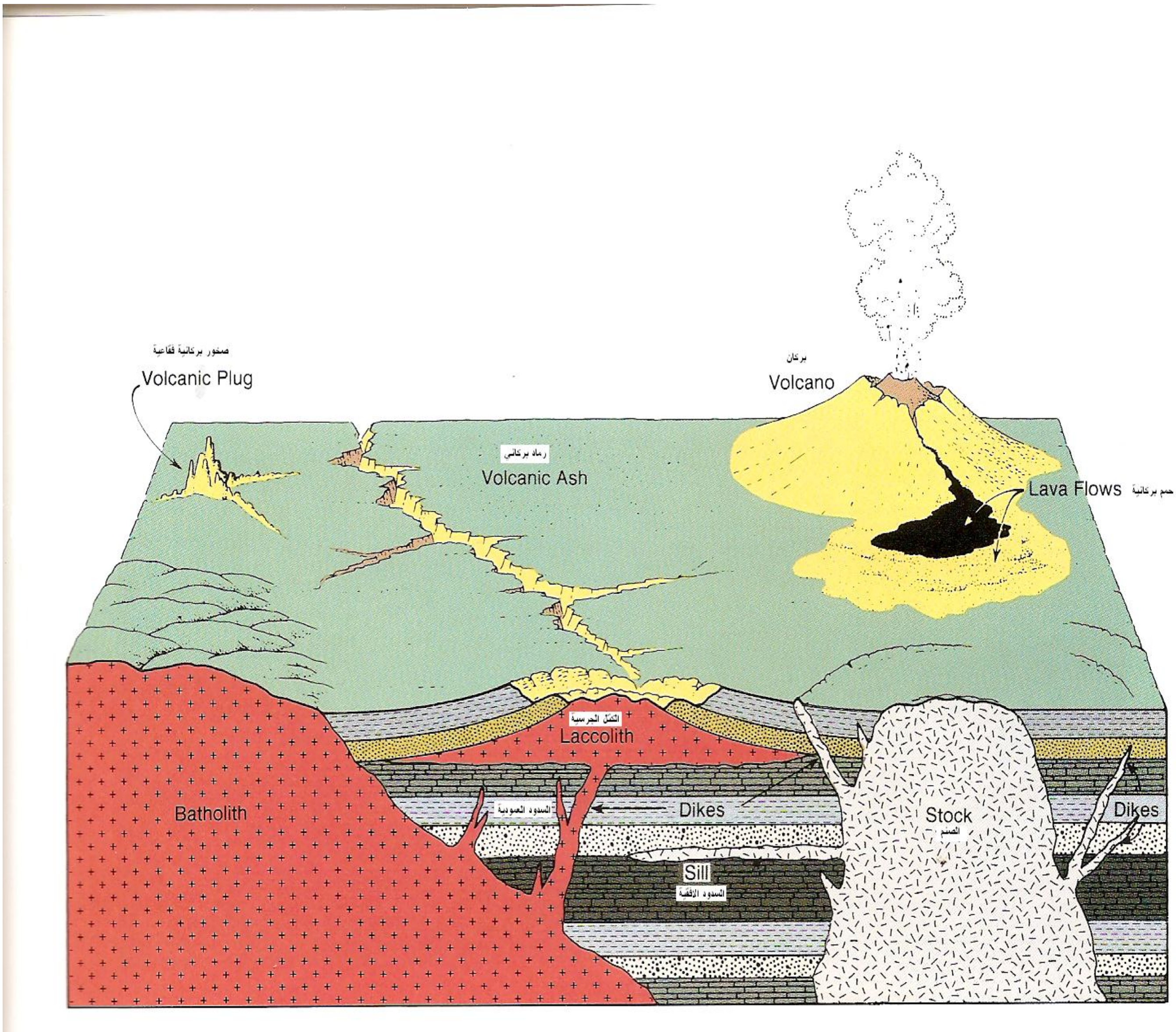



**Figure 9: The structure forms of Igneous Rocks>**

## SEDIMENATARY ROCKS:

The total amount of sedimentary rocks that exists in the upper 16 kilometers of the earth's crust is estimated to be only about 5%. These rocks are found chiefly as an extensive cover over the continents. "Sedimentary rocks" are formed by consolidation and cementation of sediments deposited under water. Sedimentary rocks also include the rocks formed by accumulation of chemically precipitated or organically derived material. Sedimentary rocks occur in layers and frequently contain fossils.

## FORMATION OF SEDIMENTARY ROCKS:

The formation of sedimentary rocks takes place in three stages (figure: 9):

(1) Weathering and erosion of preexisting rocks.

(2) Sedimentation.

(3) Lithification and diagenesis.

**Weathering and Erosion:** During weathering and erosion, the preexisting rocks and their constituent minerals are broken down. The material thus produced is called the "sediment". The sediments are usually transported and deposited in areas of accumulation by the action of water or less frequently by glacial or wind action. During transportation, the sediments are roughly sorted and deposited according to size. Bigger rocks fragments, such as gravel, settle first, sands are next in order and clays are deposited in the last. The minerals which are dissolved by the water, travel in solution.

**Sedimentation:**The process of accumulation of sediments at a site of deposition is called the "sedimentation". The material carried in solution precipitates and accumulates. Sedimentation is the intermediate stage in the formation of sedimentary rocks.

**<u>Lithification and Diagenesis</u>:** "Lithification" is a process by which soft and loose sediments are converted into hard and firm rocks. This process is also called "consolidation". During this process many physical and chemical changes take place within the sediment. Such changes are called the diagenetic changes and the Process is described as "diagenesis"' The diagenesis includes three processes : (1) compaction, (2) cementation, and (3) recrystallization.

(1) **Compaction.** Compaction occurs when the weight of overlying layers compresses the sediments below, As the grains of sediments are pressed closer and closer together, there is considerable reduction in pore space and volume. Fine grained sediments, such as clays are consolidated more effectively by this process.

(2) **Cementation.** When water circulates through the pores of coarse grained sediment, dissolved mineral matter is precipitated between the grains which causes cementation. The most commoncementing materials are silica calcium carbonate, iron oxides andclay minerals. The identification of the cementing material is relatively simple matter. Calcite cement will effervesce with dilutehydrochloric acid, while iron oxide gives the rock a characteristic red, orange or yellow colour. Silica the hardest of the cements,produces the hardest sedimentary rocks.

(3) **Recrystallization.** Although most sedimentary rocks are lithifiedbycompaction, cementation or a combination of both, some are consolidatedchiefly by the recrystallization of their constituents. Chemicallyformed rocks, such as limestone,dolomites, salt and gypsum are the examples of the rocks consolidated by recrystallization.

## <u>CLASSIFICATION:</u>

The sediments from which sedimentary rocks are formed, may bedivided into two major groups :

(1) clastic sediments.

(2) non-elasticsediments.

## Clastic Sediments:

"Clastic sediments" are broken fragments of preexisting rocks rangingin size from minute clay particles to very large boulders. Clastic rocks areformed by the mechanical accumulation of grains of clastic sediments.Depending upon the size ofconstituent grains, the clastic rocks areclassifiedinto three groups:

(1) Rudaceous rocks.

(2) Arenaceous rocks.

(3)Argillaceous rocks.

**Rudaceous Rocks:** These rocks are formed by accumulation of biggerrocks fragments such as gravels, pebbles and boulders. If the grains arerounded, the rock is called "conglomerate"' and if they are angular, therockis termed as "breccia".

**Arenaceous Rocks:** These rocks are composed almost entirely of sandgrains, when individual grains are rounded, the rock is called "sandstone", and grit if the grains are angular.

**Argillaceous Rocks:** These rocks are made up of very fine grained sediments. "Shale" and "mudstone" are typical argillaceous rocks which are composed of clay-sized sediment.

There are. Someclastic rocks which do not fit into the above said classification. They require consideration of mineral composition also. For example, when appreciable quantities of felspars are present in a sandstone, the rock is called "arkose". When the sandstone contains an appreciable quantity of clay as well as angular quartz grains' the-rock is called "graywacke". In addition there are many clastic rocks which contain grains of more than one size. For example, a rock containing a mixture-of sand and silt may be classified as "sand siltstone" or "silty sandstone" depending on which Particle size dominates.

## Nonclastic Sediments:

Nonclastic rocks include those sedimentary rocks which are formed bychemicalprecipitationofmineralsfrom water or byaccumulationofremainsof animals and plants. They are classified into two groups :

(1) Chemicallyformed rocks.
(2) Organically formed rocks.

**Chemically Formed Rocks:** These rocks are formed when mineralmatter in solution is precipitated from water, usually because ofchangesinwater temperature or in the chemical content of water. Such chemical sedimentsarederivedfromthedissolutionofmaterialsfromolderrocksands ubsequent transportation of dissolved chemical substances into a sea orlake. On the basis of composition' the chemically formed rocks are classifiedas follows.

**(1)Carbonate Rocks -** "Limestones" and "dolomites" are the mostabundant carbonate rocks,they are formed by the chemicalprecipitation of calcium carbonate from sea water.

**(2)Salt Rocks -** Evaporation is the major process involved in thedeposition of chemical precipitates. The salt deposits formed bytheevaporationofsalinelakesarecalledthe "evaporates".The principalmineralsofthesedepositsarechloridesandsulfatesof Na, K, Mg and Ca. Rocksalt, gypsum and anhydrite are by farthe most abundant minerals of evaporates.They commonly formmassive beds.

**(3)Ferruginous Rocks -** This group includes those rocks which are formedbythechemicalprecipitationofironoxides.Suchrockscontain a high proportion of iron-bearing minerals such as siderite, hematite,chamosite and pyrite.

**(4)Siliceous Deposits -** Siliceous rocks are formed when silica isprecipitated from water. Examples of such deposits are flint,chert, jasper and agate.

**Organically Formed Rocks:** These rocks are composed mainly of remains of animals or plants. organically formed rocks are subdivided into two groups :

(1) Biochemical rocks.

(2) Organic rocks.

(1) **Biochemical Rocks -** The biochemical sediment is producedwhenplants and animals living under water, extract from it dissolvedmineralmatter, usually calcite, to form shells or other hardparts.These shells accumulate on the ocean floor in great quantities toform sedimentary rocks. An example of the biochemical rock is"shell - limestone".

(2) **Organic Rocks -**Rocks containing organic matter belong to thisgroup. An example of such rocks is ,,coal'. These are also called the " carbonaceous rocks".

## TEXTURE:

"Texture" means the size, shape and arrangement of grains in a rock.As sediments contain particles of various size, grain size is an importantfactor for the description of sedimentary rocks. Depending upon the size,particles of sediments are classified into pebbles, gravels, sand, silt andclay,and each of these gives rise to a particular type of rock. This classificationis shown in Table 5.

**Table5: Particle Size in Sediments.**

| Grade | Grain Size | Rock Type |
|---|---|---|

| | | |
|---|---|---|
| Pebble<br>Gravel | l0mmandabove<br>2 mm to 10mm | Conglomerate |
| Sand | 0.1 mmto 2 mm | Sandstone |
| Silt | 0.01 mm to 0.1 mm | Siltstone |
| Clay | Less than 0.01 mm | Shale |

The grain size of sands varies from 2 mm to 0.1 mm. They are subdivided into four groups :

(1) "very coarse sand" (grain size more than 1.0 mm).

(2) "coarse sand' (grain size 1 to 0.5 mm).

(3) "medium sand" (grain size 0.5 to 0.25 mm) .

(4) "fine sand' (grain size 0.25 to 0.1 mm).

Sediments which contain grains of various grades in nearly equalamount are said robe " unsorted’. Onthe other hand, sediments containingmainly grains of one grade only, are said to be "well sorted" or "graded" The degree of assortment may be high in many wind deposits and in sedimentsdeposited on gently sloping sea floors. Stream deposits are commonlyless well graded. Glacial deposits are generally unsorted.

The shapes of the constituent grains of sedimentary rocks are orconsiderablesignificance in the study of texture. The grains of a rock may berounded, partially rounded or angular. Grains which have been transportedto considerable distances commonly show a high degree of rounding whereas grains that have resulted from disintegration, volcanic explosion orglacial action are commonly angular. In breccias the rock fragments areangular while in conglomerates, they are rounded.

The chemically formed rocks may contain rounded concretions. If theyare of the size of a pin head (size 1 mm), the texture of the rock is said tobe"oolitic", and if they are of the size of a pea, the texture is described as"pisolitic".

The texture and mineral composition of sedimentary rocks are of greatvalue in determining the nature of the environment at the time when thesediment was deposited. A conglomerate, for example, indicates a highenergyenvironment,such as a swiftly flowing stream where only the coarsematerial can be deposited. The arkose suggests a dry climate where littlechemical alteration of felspar is possible. Carbonaceous shale indicates alow energy, organic rich environment' such as swamp or lagoon.

## STRUCTURAL FEATURES:

The important structural features of sedimentary rocks are stratification,lamination, graded bedding, current bedding and ripple marks. Besidesthese, there are some minor structures such as mud cracks, rain prints, tracksof terrestrial animals, etc. These structures give clues to the past environment.

**Stratification-** All sedimentary rocks are, in general, characterized bystratification. Deposition of sediments into layers or beds is called the"stratification"(Fig.10 a)The planes dividing different beds are called the "beddingplanes". The thickness of a bed may vary from a few centimetersto many meters. Different beds are distinguished from each other by (1) difference in mineral composition, (2) variation in grain size or texture, (3)difference in colour, and (4) variation in thickness.

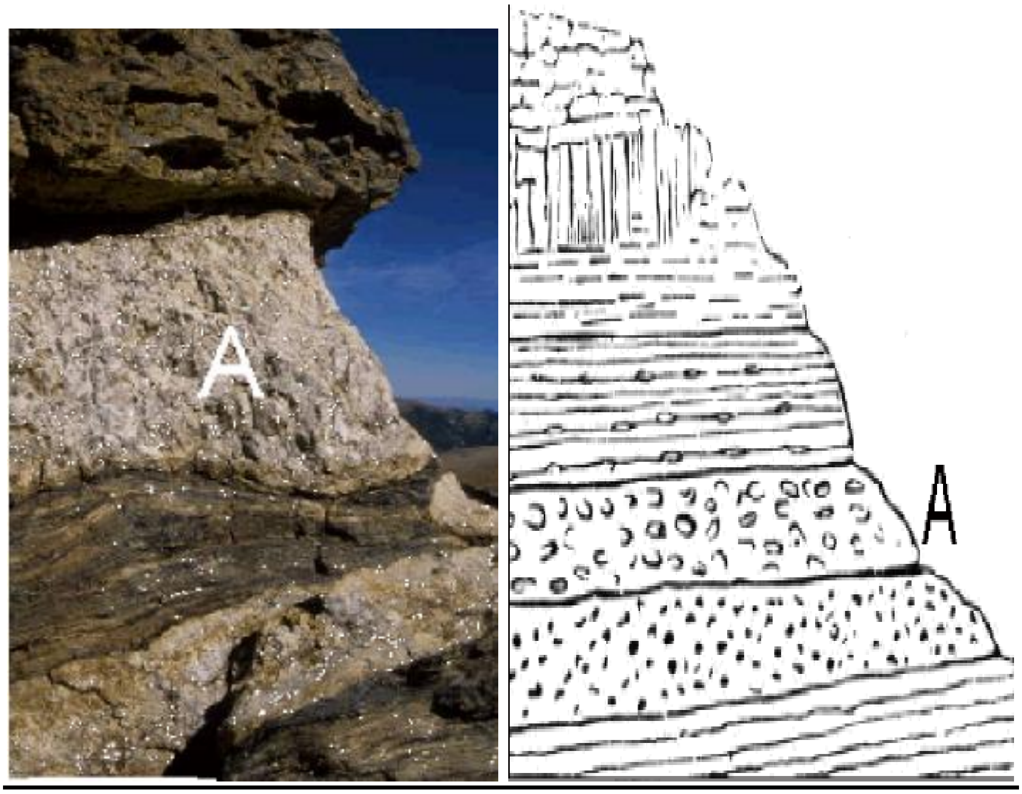
**Lamination-**Thin bedding, less than one ▫ centimeter in thickness, are called "lamination'. Lamination is usually found in very fine grained rocks like shale and gives them the characteristic Fig.9. Stratification. Bed 'b' shows lamination. property of fissility. In laminated rocks, the clay and other flaky minerals tend to lie with their flat surfaces parallel to the plane of lamination. It should be noted that lamination refers to parallel arrangements of minerals within a bed whereas stratification refers to a succession of beds separated by bedding planes.

**Graded Bedding -** In "graded bedding" each bed shows a gradation in grain size from coarse below to fine above(Fig.10 b).The graded bedding results from rapid sedimentation in water. This structure is commonly found in graywackes. The bottom of a graded bed generally lies on shale andmay consist of a coarse grit.It than shows an upwardtransition towards finermaterial. At the top it commonly ends in shale.

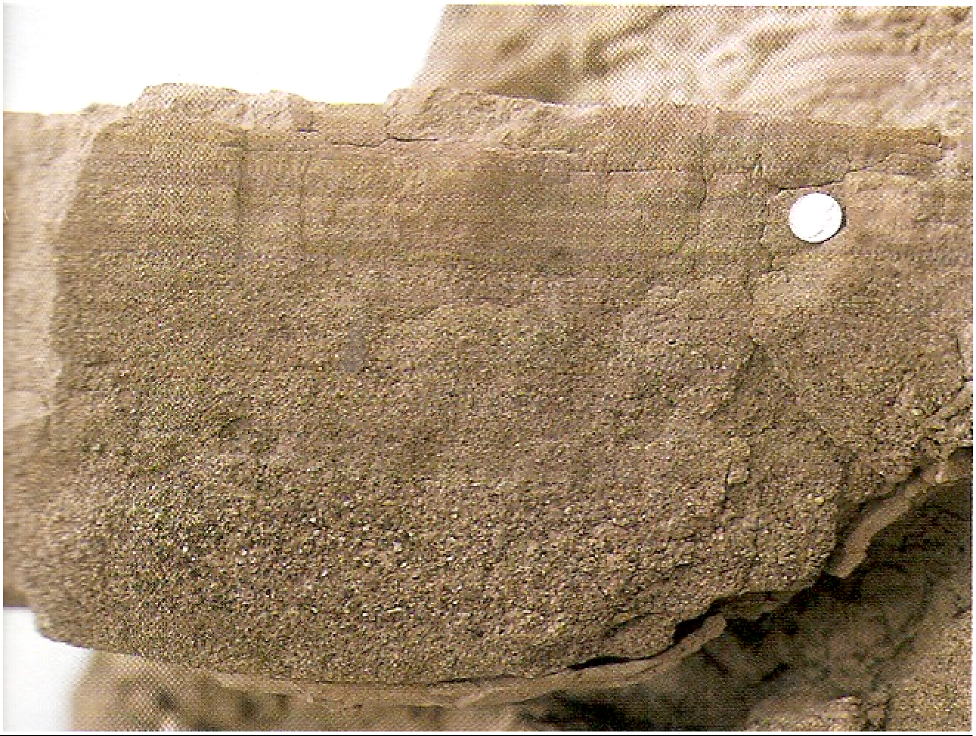
**current Bedding-** current bedding is also called the "cross bedding". In this structure minor beds or laminations lie at an angle to the planes of general stratification .These minor beds commonly terminate abruptly at the top where they are overlain by the next current bedded deposit. Current bedding is commonly found in shallow water and wind formed deposits(Fig.10 c,d). This structure indicates rapid changes in the velocity and direction of flow of streams or wind carrying sediment. In current bedding, the minor beds are inclined and stacked upin the forma wedge in the direction of water currents or prevailing wind.

**Ripple Marks -**" Ripple marks" are the wavy undulations seen on the surface of bedding planes .They are produced by the action of waves and currents in shallow water. This structure may also be formed on the surface of deposits formed by wind. Ripple marks are of two types : (1) asymmetrical or current ripple marks, and (2) symmetrical or oscillation ripple marks. The oscillation ripple marks are useful in determining top and bottom of deformed beds.

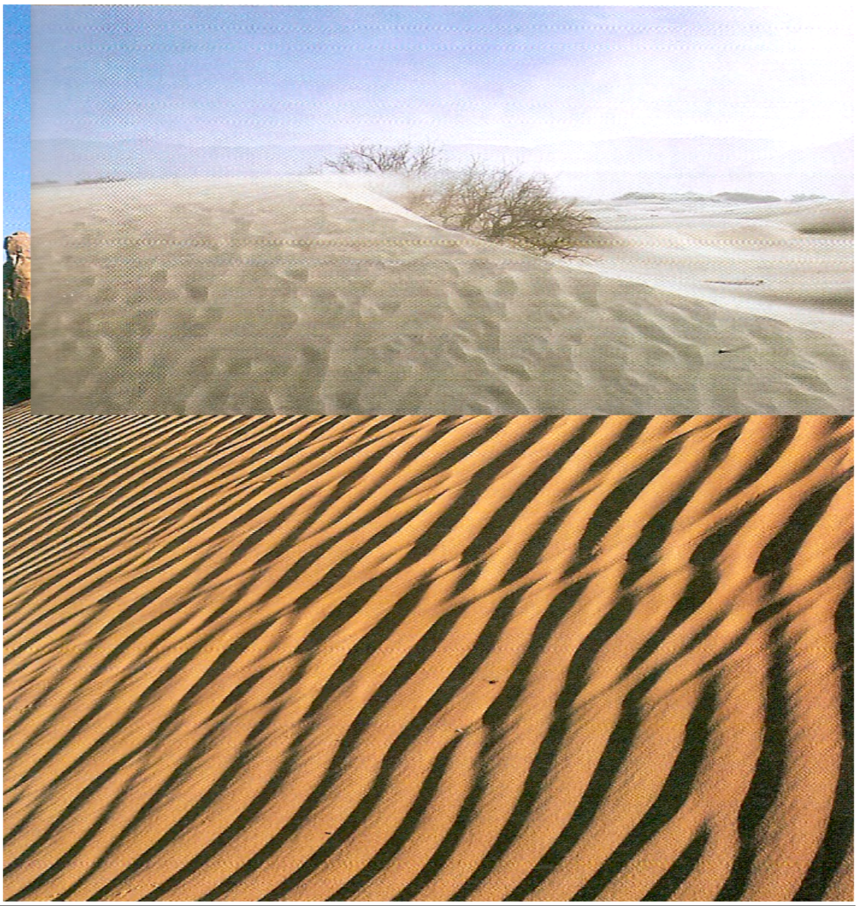
**Minor Structures -** The surface of bedding planes may show some minor structures such as mud cracks(Fig.10 e), rain print, and tracts and trails of animals. These structures are commonly preserved as casts' "Mud cracks" are often found in the fine grained sedimentary rock rocks that have been exposed to drying under sub-aerial conditions. They network of fissures enclosing polygonal areas. Mud cracks are characteristic of the flood plains of large rivers. A "rain print" is a slight shallow depression rimmed by a low ridge which is raised by the impact of the rain drop. It is formed when a brief rain shower falls on a smooth surface of fine grained sediment. "Tracks and trails" are the markings indicating the passage of some animal over soft sediment. All these minor structures if found in formations that have been disturbed by severe folding, are of great help in determining the top and bottom of beds.



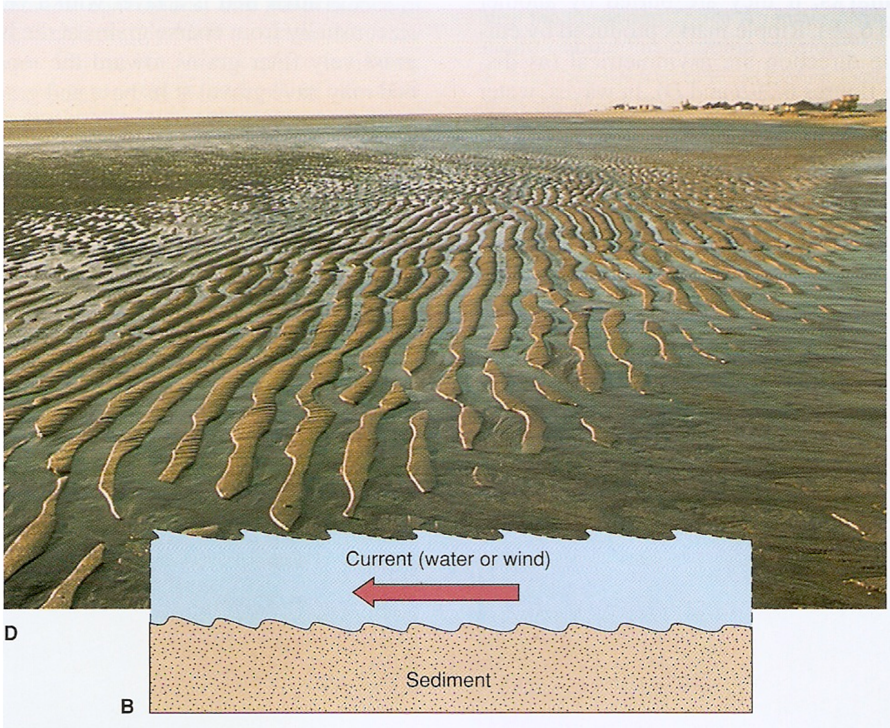

**aStratification**



**b: Graded bedding**



**c:Cross bedding(current bedding)by wind**




**d:Cross bedding by water**

**e:Mud cracks**

**Figure 10 a,b,c,d,e: Structures of sedimentary rocks**

## Sedimentary Rock types:

### Conglomerate

Nature. Consolidated gravels Colour variable'

Mineral Composition. Rounded pebbles are set in a fine grained matrix.The matrix commonly consists of sand or silt and it is cemented by silica, calcium carbonate or iron oxide. The individual pebbles may be entirelycomposed of quartz or may be rock fragments that have not been decomposed.

Texture. Very coarse grained.

varieties. Fine conglomerates grade into coarse sandstones. If the rockcontains angular or subangularfragments, it is called "breccia". The angularityof rock fragments in breccia suggests that this material could nothave travelled very far from its source.

### Sandstone

Nature.Arenaceous.Colour variable according to the type of cementing material. Rocks having silicaor calcite as their cementing material are lightin colour, those that iron oxide are red to reddish brown.

Mineral composition. Quartz is the chief mineral constituent. Small amount of feldspar, mica, garnet, etc. may also occur. Cementing material may be silica, calcite, iron oxide, clay or chlorite.

Texture. Sandstone are composed almost entirely of well sorted, subangular to rounded sand grains. The texture of sandstone is : (1) "coarsegrained' when the size of grains is between 2 to 0.5 mm, (2) "medium grained" when the size of grains is between 0.5 to 0.25 mm, and (2) "fine grained ", when the size of grains is between 0.25 to 0.l mm.

Structure. The common structure seen in the sandstones are stratification,current bedding, ripplemarksand rain prints.

Varieties. (1) **Orthoquartzite.** White siliceous sandstones in which most of the grains as well as cement consist of quartz, are called orthoquartzite. (2)**Grit.** It is a sandstone containing sharply angular grains. (3) **Arkose.**Acoarsegrained sandstone containing notable amounts of felspar is called arkose. (4)**Graywackes.**It is a grey coloured rock containing poorly sortedangular fragments of quartz and basic igneous rocks, and line grainedchloriteor clay material. Graywackes may contain as much as 30%finegrained clay or chlorite or both. The finer grained grawackes grade into theshales. (5) **Glauconite sandstone.** It is a greencoloured sandstone containing a mineral called glauconite.

**Shale**

Nature.Argillaceous.Colour variable. Shales are often soft and can bescratched by a knife.

Mineral Composition.Shalesare composed mainly of clay minerals likekaolinite, montmorillonite and illite. Small amounts of other minerals suchas quartz, mica and chlorite are also present.

Texture. Very fine grained with grain size less than 0.01 mm.

Structure. Lamination, ripple marks and some organic structures maybe present.

Varieties. (1) **Calcariousshale.**When considerable amount of calcium carbonate is present. (2) **Ferruginous shale.**When considerable amount ofiron oxide is present. (3) **Carbonaceous shale.**When considerable amountof carbonaceous (organic) matter is present.(4)**Sillstone.** It is a rockcontaining compact silt (grain size 0.01 to 0.1 mm). (5) **Mudstone.** It is astructureless rock containing compacted mud.

**Limestone**

Nature, Calcareousrock.Formed chemically or organically.Commonlywhite, grey or creamcoloured. Often contains fossils. Limestones are identifiedby their softness, fossil content and effervescence in dilutehydrochloric acid.

Mineral Composition.Calcium carbonate in the chief constituent. Magnesium carbonate is also present is variable amounts. Chalcedony, siltand clays are present as impurities. Some limestonesmay also containcalcareous shells of marine animals.

Texture. Limestone is a fine grained rock. It is commonly compact andmassive. Some limestones may have oolitic structure. Organic structures arealso common.

Varieties. The important varieties of limestones are as follows. (1) **Chalk.** The porous tine grained and generallyfriable limestone composedmainly of foraminiferalshells, is know as chalk. (2) **Oolitic limestone.**Thislimestone is mainly composed of rounded grains resembling fish roe. It isbelieved to have been formed by chemical precipitation. Under the microscopeeach grain (Oolith) is seen to be made up of concentric layers ofCaCOr, often with a bit of shell at the centre. (3) **Marl.** Impure limestonesin which the percentage of clay and calcium carbonate is almost equal, areknown a "marl".

**Dolomite**

Nature. Dolomites resemble limestones.

Mineral Composition. The chief constituent of dolomite rock isdolomite mineral [$CaMg(CO_3)_2$]. It may also contain some calcite,

Dolomites are generally not formed by original chemical precipitation. Theyare formed when calcium carbonate of limestone is replaced by dolomite.This process is called "dolomitization". Depending upon therelative proportion of calcite and dolomite present, the limestones and dolomites are classifiedas follows.

(1) Limestones. Those rocks which contain more than 90% calcite andless than l0% dolomite.

(2) Dolomiticlimestones. Those rocks which contain 90 - 50%calciteand 10-50% dolomite.

(3) Calcitic dolomites. The rocks which contain 5O - l0% calcite and50-90% dolomite.

(4) Dolomites.Those rocks which contain less than 10%, calcite and more than 90% dolomite.

Texture. Dolomite is a fine grained rock. It is commonly compact andmassive.

**Iron Formation**

Nature.Iron-formation is a banded iron rock. It is formed due to chemicalprecipitation of iron oxide and chert.

MineralComposition.Their no-formation consistsmainlyofchert-magnetite,chert-hematite, and chert-hematite-magnetite. Other minerals that arecommonly present are siderite, ankerite and chamosite.

Texture and Structure. In these rocks the sedimentary banding is generally well preserved.

**Laterite**

Nature.Colourisoftenred,brownoryellow.Lateriteisaresidual.product of weathering in hot humid climate. It occurs as mantle over bed rocks.

Minerals Composition. Laterites are essentially clays rich in aluminum and iron hydroxides with minor amounts of silica.

Texture.Porous and concretionary.

varieties. Laterites rich in aluminum hydroxides are called "bauxites"Bauxites commonly show' pisolitic" structure.

## METAMORPHIC ROCKS

Metamorphic rocks are formed from the older rocks when they aresubjected to increased temperature, pressure and shearing stresses at considerabledepth in the earth's crust. The older rocks may be either sedimentary,igneous or other metamorphic rocks. During metamorphismrecrystallization takes place essentially in the solid state and new mineralsand new textures are Produced. The process of change of the original rock in the composition and texture of rocks, without melting, by heat and pressure is referred to as Metamorphism.

The effects of metamorphism include:

1. Deformation and reorientation of mineral grains.
2. Recrystallization of minerals into larger grains.
3. Chemical recombination and growth of new minerals.

## Agent of Metamorphism:

The agent of metamorphism include heat, pressure and chemically active fluids:

**1.Heat as a metamorphism agent**

Perhaps the most important agent of metamorphism. In the upper crust the increase in the temperature averages about 30$^{o}$C per kilometer. Rocks may be subjected to extreme temperatures if they are buried deep within the earth or being in contact with molten materials. Consequently these rocks become unstable and gradually changes at temperature about 200 - 750$^{o}$C or more near molten materials.

**2. Pressure as metamorphism agent**

Pressure like temperature also increases with depth. Two types of pressure are:

a. Stress or Directional pressure :In which rocks are subjected to stress during the process of mountain building. Here the applied force is directional.

b. Confining or Hydrostatic pressure : In which the force is applied equally in all directions. Buried rocks are subjected to the force exerted by the load above.

**3.Chemical active fluids as metamorphism agent**

Chemically active fluids most commonly water containing ions in solution, also enhance the metamorphism process. In some instances the minerals recrystallize to form more stable state. In other cases ion exchange among minerals results in formation of completely new minerals.

## Types of metamorphism

1. **Thermal (contact) metamorphism:**
   In thermal metamorphism increased temperature is the dominant agent producing change and the degree of recrysallization of the original rocks bears a simple relation to it. It is characteristic of the country rocks that lie at the margins of any large intrusions and have been baked and altered by the hot magma. Some examples limestone is metamorphosed to marble and sand stone is metamorphosed to quartzite.
2. **Regional metamorphism**
   Temperature, load and directed pressure are important agents of regional metamorphism which invariably affects wide areas rather than being related to an individual igneous mass or one zone of movement. During mountain building rocks are subjected to the intense stresses and temperatures associated with large scale deformation. The end result may be extensive areas of metamorphic rocks.
3. **Dynamic metamorphism**
   In dynamic metamorphism, increased stress is the dominant agent, extra heat being relatively unimportant. It is characteristic of narrow belts of movement, where the rocks on side are being displaced relative to those on the other. Whether the rocks are simply crushed or whether there is some growth of new crystals

depends largely on the temperature in the mass affected by dynamic metamorphism.

## Classification of metamorphic rocks

The classification of metamorphic rocks depends on three main bases:

1. **Texture :** the degree of metamorphism is reflected in the texture and mineralogy of metamorphic rocks due to deformation and recrystallization.
2. **Chemical composition:** since metamorphic rocks may be formed from any type of existing rock , their mineral composition ranges more widely than that of all other types of rocks combined. Metamorphic rocks may contain most of the common minerals found in igneous and sedimentary rocks. Some minerals occur only or dominantly in metamorphic rocks.
3. **Foliation:**In which minerals take a preferred orientation which will be perpendicular to the direction of the compressional force. Metamorphicrocks are subdivided into two main types: foliated texture(oriented and banded) and non-foliated texture(crystalline and granular).

## Other classification of metamorphic rocks

1. **Foliated metamorphic rocks:**Rocks which are processes a definite banded structure. These rocks have texture which may cause them to break along parallel surface. Foliation is the result of rearrangement of mineral grains by rotation and recrystallization under pressure. They may be subdivided according to type of foliation.

   The degree of metamorphism is related to the condition of temperature and pressure under which the new metamorphic rock has formed and may be assessed by the appearance of certain new minerals. Textural changes also occur as metamorphic grade increases. As the metamorphism grade increases the grain size increases. At low grade metamorphism rocks are transformed to slate and phyllite for example shales and mudstone are transformed into slates and phyllites by low grade metamorphism. At medium grade metamorphism rocks are transformed to schistsAnd at high grade metamorphism all rocks are transformed to gneiss as shown in figure 11.

**<u>RockLowMediumHigh</u>**

**Shale--------------Slate------------Schist-------------------Gneiss**
**Phyllite-------- = ------------------ =**
**Rhyolite-------------------------- Schist--------------------Gneiss**
**Granite-------------------------- Schist--------------------Gneiss**
**Basalt---------------------------- Schist--------------------Gneiss**

**Figure 11 : Grade of Metamorphism of Foliated rocks.**

2. **Non-Foliated metamorphism rocks:** They are massive and structureless, lack parallelism and their mineral components are either coarse or microscopic. Marble is a metamorphic rock formed from limestone and dolomite by recrystallization. Quartzite is a metamorphic rock formed from quartz rich sand stones figure 12.

**<u>RockLowMediumHigh</u>**
**Sandstone--------------------------Quartzite**
**Lime stone-------------------------Marble**
**Shale--------------------------------Hornfels**

**Figure 12 : Grade of Metamorphism of Non-Foliated rocks.**

## <u>Metamorphic Rock types:</u>

**Slate**- Slates form at low metamorphic grade by the growth of fine grained chlorite and clay minerals. The preferred orientation of these sheet silicates causes the rock to easily break along the planes parallel to the sheet silicates, causing a *slatey cleavage.* Note that in the case shown here, the maximum stress is applied at an angle to the original bedding planes, so that the slatey cleavage has developed at an angle to the original bedding, figure13.

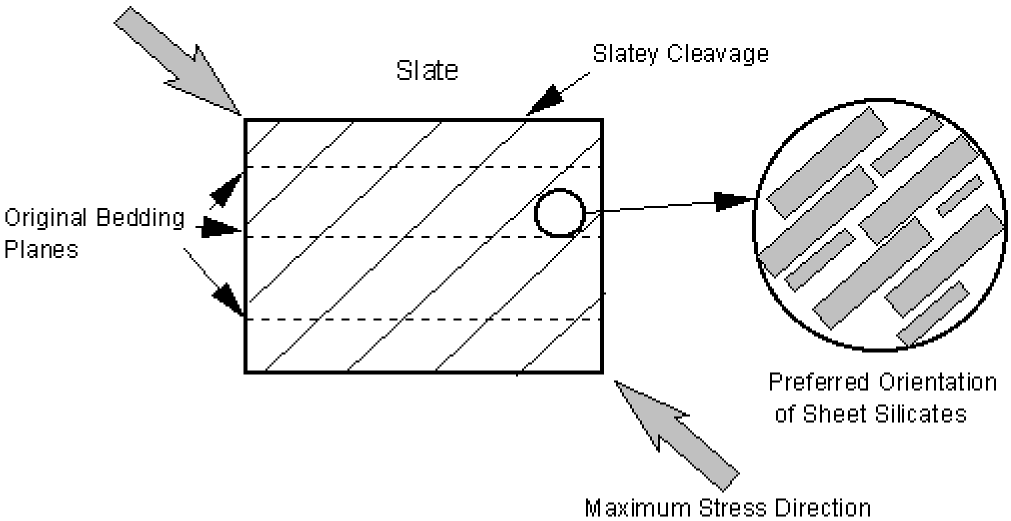



**Figure 13: The texture of slate.**

**Schist** - The size of the mineral grains tends to enlarge with increasing grade of metamorphism. Eventually the rock develops a near planar foliation caused by the preferred orientation of sheet silicates (mainly biotite and muscovite). Quartz and Feldspar grains, however show no preferred orientation. The irregular planar foliation at this stage is called schistosity, figure 14.

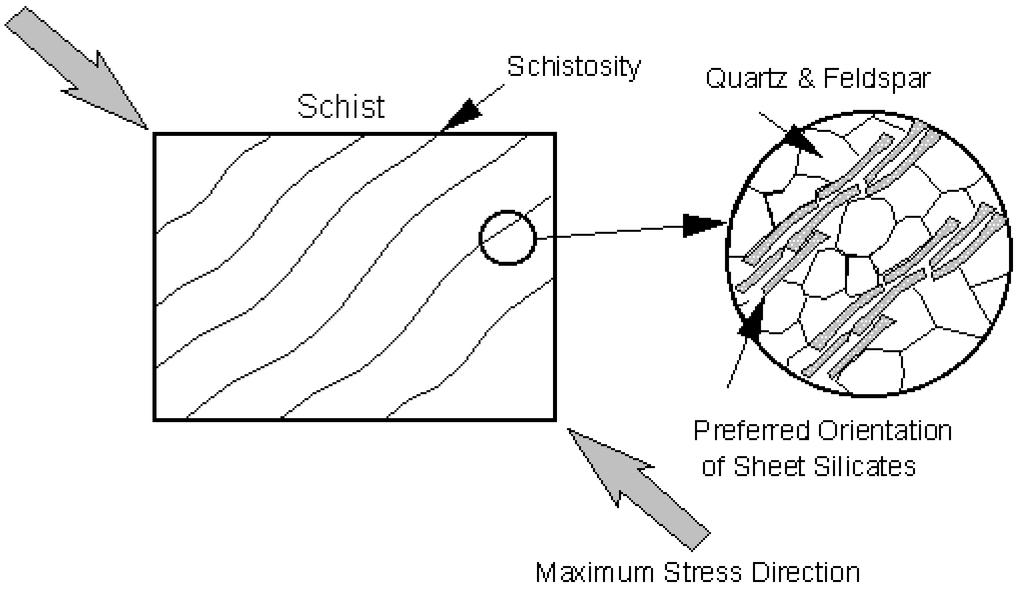



**Figure 14: The texture of Schist.**

**Gneiss**- As metamorphic grade increases, the sheet silicates become unstable and dark colored minerals like hornblende and pyroxene start to grow. These dark colored minerals tend to become segregated in distinct bands through the rock, giving the rock a *gneissic banding*. Because the dark colored minerals tend to form elongated crystals, rather than sheet- like crystals, they still have a preferred orientation with their long directions perpendicular to the maximum differential stress, figure15.

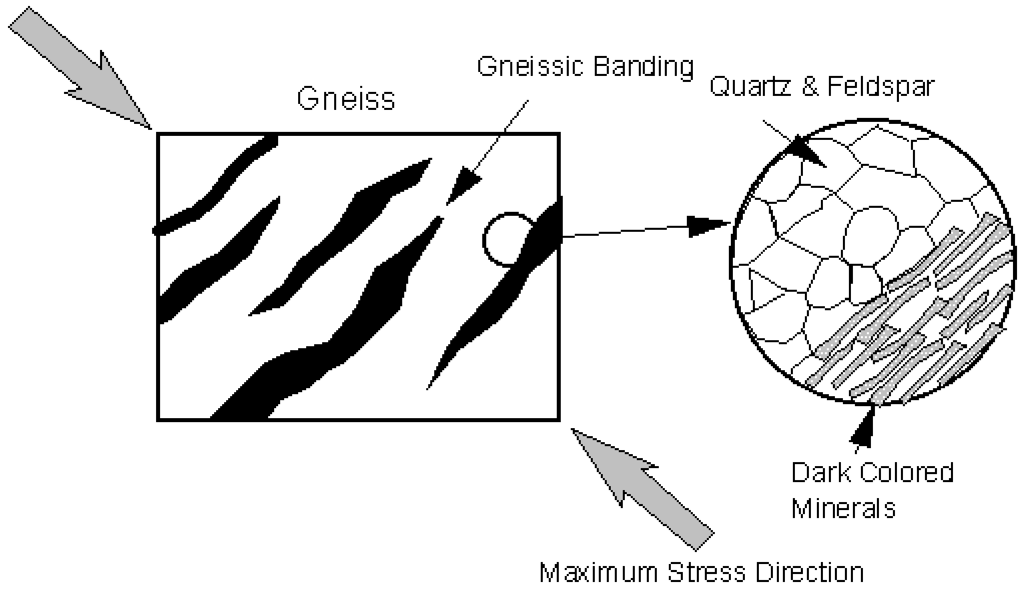



**Figure 15: The texture of Gneiss.**

**Marble** - Since limestones are made up of essentially one mineral, Calcite, and calcite is stable over a wide range of temperature and pressure, metamorphism of limestone only causes the original calcite crystals to grow larger. Since no sheet silicates are present the resulting rock, a marble, does not show foliation.

**Quartzite**- Metamorphism of sandstone originally containing only quartz, results in recrystallization and growth of the quartz, producing a non foliated rock called a quartzite.

## Rock Cycle:

The rock cycle shows the relationship between the three types of rocks, that is the igneous, sedimentary and metamorphic rocks. One type of rock changes slowly to another type. Erosion produces sediment which is transported and deposited into deep basins under the sea. Then it hardens to form "sedimentary rocks". If these rocks are deeply buried, the temperature and pressure turn them into "metamorphic rocks". Intense heat at great depths melts metamorphic rocks and produces magma. The magma may rise up and reach the earth's surface where it cools to form "igneous rocks". At the surface, igneous rocks are exposed to weathering and erosion, and the cycle begins again.

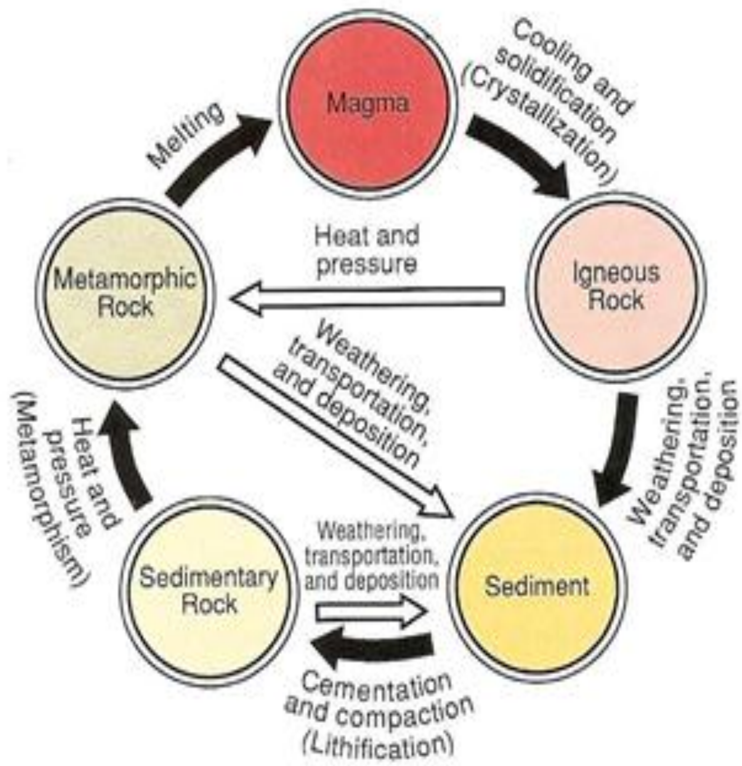



**Figure13 :The geological cycle of the rocks**