1- Introduction

1.1 The Science of Geology

The word Geology is derived from the Greek "Gea" the earth and "logoss" the science, thus it is "Earth Science". Geology is the science study of the solid earth, that examines the earth, its form and composition and the changes which it has undergone and is going. Geology deals with many practical questions about our physical environment, what forces produce different geological structures, understanding many processes that operate beneath and upon its surface. Thus geology might be called a derived science (or applied science) as its objective is the explanation of the phenomena, structures in the globe in terms of the general laws recognized by the chemists, physicists, biologists and mathematicians. So it is closely related to pure sciences (Chemistry, physics, biology and mathematics).

1.2 Branches of Earth Sciences

For the great developments that occurred in geology so it is subdivided into many branches:

1- **Petrology**: The investigation of the rocks forming the earth.
2- **Mineralogy and Crystallography**: It is the mineral constituents of rocks.
3- **Structural Geology**: How rocks are distributed and deformed.
4- **Geochemistry:** It is a study of the chemistry of rocks and the distribution of major and trace elements in rocks and minerals. This can lead to an understanding of how a particular rock has originated**,** this will lead, in the broadest sense, to a knowledge of the chemistry of the upper layers of the earth.
5- **Geological Mapping**: The distribution of rocks at the earth's surface is found by making a geological survey (that is, by ***geological mapping***) and is recorded on ***geological maps***. This information about rocks is superimposed on a topographic base map.
6- **Geophysics** : Knowledge of the nature and physical conditions of the deeper levels of the planet can be gained only by the special methods of ***geophysics*,** the twin science of geology; the term "***Earth sciences***" embraces both. From the theory and methods of geophysics, a set of techniques **(*applied geophysics*)** has been evolved for exploring the distribution of rocks of shallower levels where the interests of geologists and geophysicists are most intertwined.
7- S**tratigraphy**: The interpretation of rock layers as earth history and the knowledge of the earth at the present time raises questions about the processes that have formed it in the past: that is, about its history.
8- S**edimentology** : A study of the processes leading to the formation of sedimentary rocks.

8- **Palaeontology**: It is the study of fossils and closely linked to earth history, and from both has come the understanding of the development of life on our planet. The insight thus gained, into expanses of time stretching back over thousands of millions of years, into the origins of life and into the evolution of man, is geology's main contribution to scientific philosophy and to the ideas of educated men and women.

9- **Physical Geology**: It is the study of different geological processes (weathering, erosion and deposition).

10- **Hydrology, Hydrogeology & Geohydrology**: ***Hydrology*** is the study of water which addresses the occurrences, distribution, movement, quality and quantity of all waters of the earth. ***Hydrogeology*** encompasses the interrelationships of geologic materials and processes with water. A similar term, ***Geohydrology***, is sometimes used as a synonym of hydrogeology, although it more properly describes an engineering field dealing with subsurface hydrology.

11- **Mining & Petroleum Geology**: It is the investigation for economical mineral ores, natural gases and petroleum and their structures.

12**- Engineering Geology** : The science that links between geology and civil engineering.

13- **Environmental Geology**: It deals with environmental problems caused by geological phenomena such as ; earthquakes, volcanoes , landslides , and surface and underground water contamination.

14- **Marine Geology**: It deals with marine sediments and their associated phenomena, petroleum resources using marine geophysical methods.

15- **Remote Sensing**: It deals with investigation and identification of natural earth resources by means of satellites and airborne surveys.

16- **Volcanology**: It deals with the study of volcanoes, their formation , types and distributions.

17- **Glaciology**: It deals with the study of glaciers , their types and distributions.

18- **Geochronology** : It is the science of estimating ages using radioactive elements.

1.3 Relevance of Geology to Civil Engineering

The application of geological principles in engineering investigations has a great benefits for engineering sciences and vice versa for geological sciences in case of well drilling. So both are closely related and are important in site investigations. The cooperation between geologists and civil engineers resulted in introduction of " ***Soil Mechanics***" science. ***Soil mechanics*** is the branch of science that deals with the study of the physical properties of soil and the behavior of soil masses subjected to various types of forces. ***Soils engineering*** is the application of the principles of soil mechanics to practical problems**.**

Geotechnical engineering is the subdiscipline of civil engineering related to ***site investigation*** that involves natural materials found close to the surface of the earth. It includes the application of the principles of ***soil mechanics and rock mechanics*** to the design of foundations, retaining structures, and earth structures.

In a major engineering project, geological proposals might be carried out and reported on by a consultant specializing in geology, geophysics or engineering (with a detailed knowledge of ***soil or rock mechanics***). However, even where the services of a specialist consultant are employed, an engineer will have overall supervision and responsibility for the project. Therefore, the civil engineers must therefore have enough understanding of geology for the following reasons:

1- To know how and when to use the expert knowledge of consultants, and to be able to read their reports intelligently, judge their reliability, and appreciate how the conditions described might affect the project.

2- In some cases the engineer can recognize common rock types and simple geological structures, and knows where he can obtain geological information for his preliminary investigation.

3- When reading reports, or studying geological maps, he must have a complete understanding of the meaning of geological terms and be able to grasp geological concepts and arguments.

4- Most civil engineering projects involve some excavation of soils and rocks, or involve loading the earth by building on it.

5- In some cases, the excavated rocks may be used as constructional material, and in others, rocks may form a major part of the finished product, such as a motorway cutting or the site for a reservoir.

6- The feasibility, the planning and design, the construction and costing, and the safety of a project may depend critically on the geological conditions where the construction will take place.

7- In modest projects, or in those involving the redevelopment of a limited site, the demands on the geological knowledge of the engineer or the need for geological advice will be less, but are never negligible. Site investigation by boring and by testing samples may be an adequate preliminary to construction in such cases.

8- Besides, the knowledge about the geological works of rivers and the occurrences of underground water are required .

9- The exploration of a site to assess the feasibility of a project , to plan and design appropriate foundations, and to draw up bills of quantity for excavation normally requires that most of the following information be obtained:

a- what rocks and soils are present, including the sequence of strata , the nature and thicknesses of superficial deposits and the presence of igneous intrusions;

b- how these rocks are distributed over , and under , the site (that is , their structure);

c- the frequency and orientation of joints in the different bodies of rock and the location of any faults;

d- the presence and extent of any weathering of the rocks, and particularly of any soluble rocks such as limestone;

e- the groundwater conditions, including the position of the water table , and whether the groundwater contains noxious material in solution , such as sulphates, which may affect cement with which it comes in contact;

f- the presence of economic deposits which may have been extracted by mining or quarrying, to leave concealed voids or disturbed ground; and

g- the suitability of local rocks and soils, especially those to be excavated, as construction materials . Special information such as the seismicity of the region or the pattern of sediment movement in an estuary may also be required.

Much of this exploration, particularly the making of geological maps, is normally carried out in large projects by a professional engineering geologist. In limited sites the engineer may have to collect his own geological data, and make elementary, but crucial, geological decisions on, for example, whether or not a boring has reached bedrock, or has struck a boulder in the overlying till.

REVIEW QUESTIONS

1.1 Define the term "geology". Is it a pure or an applied science and why?

1.2 Show the relation of geology with the following sciences:
- a- Biology
- b- Chemistry
- c- Civil engineering
- d- Hydrology
- e- Physics

1.3 What are the main applications of geology in engineering investigations?

1.4 List some geological branches that are closely related to civil engineering.

1.5 What are the main information required for exploration of a site to assess the feasibility of a project?

1.6 What are the main reasons lead the civil engineers to get enough understanding of geology ?

1.7 Contrast between the following items:
- a- Hydrogeology and geohydrology.
- b- Geophysics and physical geology.
- c- Geophysics and remote sensing.
- d- Soil mechanics and rock mechanics.
- e- Geotechnical engineering and soil mechanics.
- f- Mining and quarrying.

2. Earth Structure

2.1 Earth Envelopes

The earth physical environment is traditionally divided into five major envelopes, these are:

1- **Atmosphere**: The outer gaseous envelope (***Air envelope***).
2- Hydrosphere: The aqueous envelope (***Water envelope***).
3- Lithosphere: The outer solid earth envelope up to 100 km (mainly earth crust and uppermost of mantle).
4- Biosphere: The livings envelope.
5- Interior of the Earth : Extending from lithosphere to center of the earth (mainly earth mantle and core).

2.2 Solid Earth Envelopes

The principal divisions of solid earth include (Fig. 2.1):

1- **Earth Crust** : consists of continental and oceanic crust separated by ***Conrad discontinuity***.
2- Earth Mantle : subdivided into ; upper mantle , transition and lower mantle . Earth mantle is separated from earth crust by ***Moho Discontinuity*** .
3- Earth Core : subdivided into outer core (liquid state) and inner core (solid state). Earth core is separated from earth mantle by ***Gutenberg Discontinuity.***

The internal structure of the earth is subdivided according to seismological information. When an earthquake occurred, two main waves will be generated namely primary waves (***P***-wave) which transfer in both liquid and solid media and shear waves (***S***-wave) which transfer in solid medium only. ***P*** and ***S*** wave velocities will be varied with respect to change in density and elastic properties that are resulted from temperature and pressure changes leading to chemical and mineralogical variations. So, according to these facts the interior of the earth has been divided to the above mentioned envelopes. The boundary between these envelopes which indicates to changes in properties is called discontinuity.

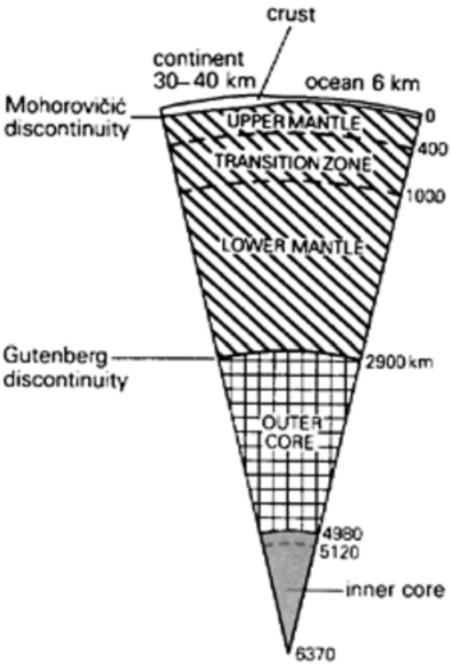


Fig. (2.1). Layers of the earth and its major discontinuities.

2.2.1 Earth Crust

The crust extends from earth surface to the mantle (***Moho or M-discontinuity***). The crust is subdivided into two parts (Table 2.1):

a- **Outer** – known as ***Sial*** (Silica-Alumina) or ***granitic layer***.
b- **Inner** – known as ***Sima*** (Silica-Magnesia) or ***basaltic layer***.

Table (2.1). Earth structure and its discontinuities.

1- Earth Crust	**Continental Crust**	**Conrad Discontinuity**
	Oceanic Crust	**Moho Discontinuity**
2- Earth Mantle	**Upper Mantle** **Transition** **Lower Mantle**	**Gutenberg Discontinuity**
3- Earth Core	**Outer Core (liquid)** **Inner Core (solid)**	

Sial or granitic layer is composed of less dense materials. It is rich in silica (SiO_2) and alumina (Al_2O_3)and has got similarity in composition of rock granite with an average density 2.7 gm/cm^3 and average thickness 25 km. Whereas, ***Sima or basaltic layer*** is made up of dense, dark colored materials which is rich in magnesia (MgO) plus silica and it is similar to those which comes out of the volcanoes with an average density 2.9 gm/cm^3 average thickness 20 km (Fig. 2.2).

The depth of the crust which includes basaltic as well as granitic layer is about 40 - 50 km in the continental areas, whereas the depth of basaltic, which forms the floor of ocean under oceanic areas, about 5 km due to the absence of the continental crust. The boundary between upper and lower crust is called ***Conrad discontinuity***.

Engineers divide the crust into rocks and soils, whereas geologists often call ***"rock"*** to all constituents of the earth crust.

The mass of the crust is about 0.7% of earth mass with an average density 2.8 gm/cm ^{3} with composition (up to 15 km) of 95% igneous rocks, 4 % shales, 0.75% sandstones and 0.25 % limestones neglecting metamorphic rocks.

The mineralogical composition of the crust consists of more than 2000 minerals, but 99.9% of the crust consists mainly 20 minerals, mainly feldspar, silica, oxides, carbonate, phosphates, sulphides, chlorides. The percentage of these minerals as follows: 60% feldspar, 12% quartz, 4.1% iron oxides and titanium, 3.8% mica, 2.6% olivine, 2.6% pyroxene, 1.4% muscovite and 3.5% other minerals.

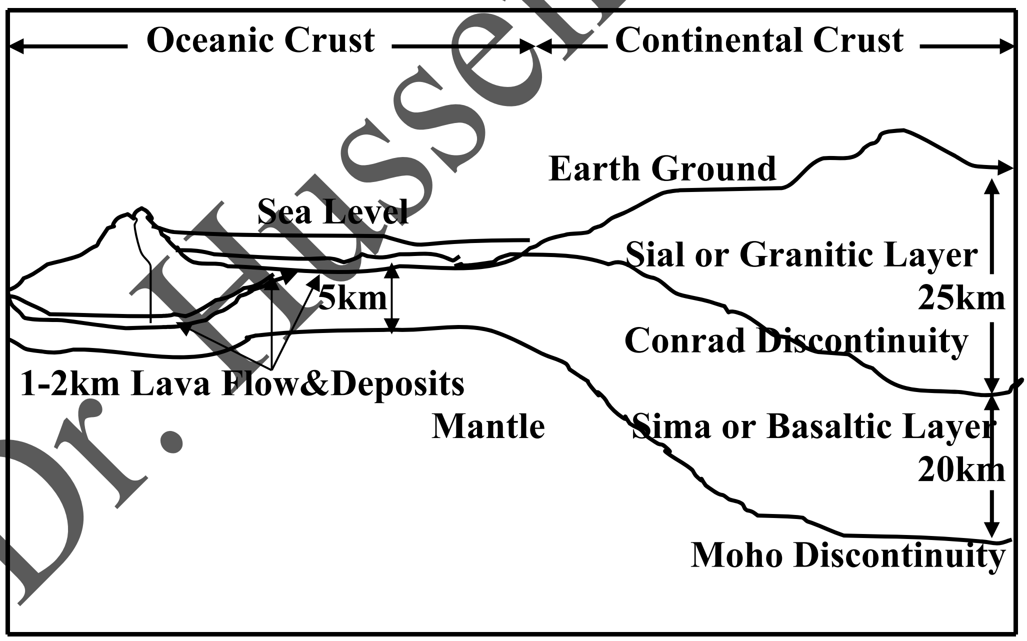


Fig. (2.2). Earth crust subdivisions.

2.2.2 Earth Mantle

It extends from ***Moho discontinuity*** to about 2900 km which is the boundary of mantle-core that is identified by ***P***-wave observations. The materials in mantle are about two or three times as dense as those of earth surface. It is believed that its composition is similar to peridotite rock with high density. The average density is about 4.5 gm/cm^3. From seismic observations, it has been found that a major change or discontinuity occurs at the boundary between mantle and outer core named ***Gutenberg discontinuity***.

2.2.3 Earth Core

It is located below Gutenberg discontinuity from depth 2900 km to earth center. It is subdivided into two parts:

a- Outer Core: It surrounds the inner core which is liquid, its composition is similar to that of the inner core, mainly iron and nickel. It is of 2100 km in thickness and average density 10-15 gm/cm^3.

b- Inner Core: It is estimated to be of about 850 km in thickness. It is solid with the same composition and contains very high density materials with an average density 17 gm/cm^3.

2.3 Variations of Physical Conditions with Depth

The earth materials are believed to be formed from the transformation of the original liquid materials to solid state as the lower density rocks are in the upper part of the earth such as acidic rock "granite" while rocks with higher densities are in the lower part as the basic rock "basalt". Thus the iron and heavy minerals proportion (such as nickel) increases with depth down to the earth core which gives an explanation for the gradual increase in rock densities downward the earth center.

The variations of some physical conditions (pressure, temperature, density and seismic velocities) with depth from earth surface are shown in Figure 2.3. It is observed that the pressure (Fig. 2.3-I) increases gradually with increasing depth due to increasing rock column. While the temperature (Fig. 2.3-II) increases quickly with depth in the upper part (crust rocks) but with gradual increase downward to the earth core reaching 5000◦C in core rocks. For density (Fig. 2.3-III), it increases gradually with depth (with about 1gm/cm^3 per 1000km depth), but with abrupt increase abruptly at the core boundary due to the presence of iron and nickel which are the main components of the core. Concerning seismic wave velocities (Fig. 2.3-IV), it is observed the increase in ***P*** and ***S***-wave velocities due to its transport from the ***continental (granitic)*** layer to the ***oceanic*** (***basaltic)*** layer. In the mantle, the increase becomes sharply reaching more than 8 km/sec for ***P***-wave (and more than 5km/sec for ***S***-wave). In the core, ***P***-wave velocity decreases in the outer core, with the absence of ***S***-wave that confirms the liquidity state of the outer core. In the inner core, ***P*** and ***S*** wave are present and increase with depth reaching more than 11.5 km/sec for ***P***-wave velocity and about 3 km/sec for ***S***-wave velocity.

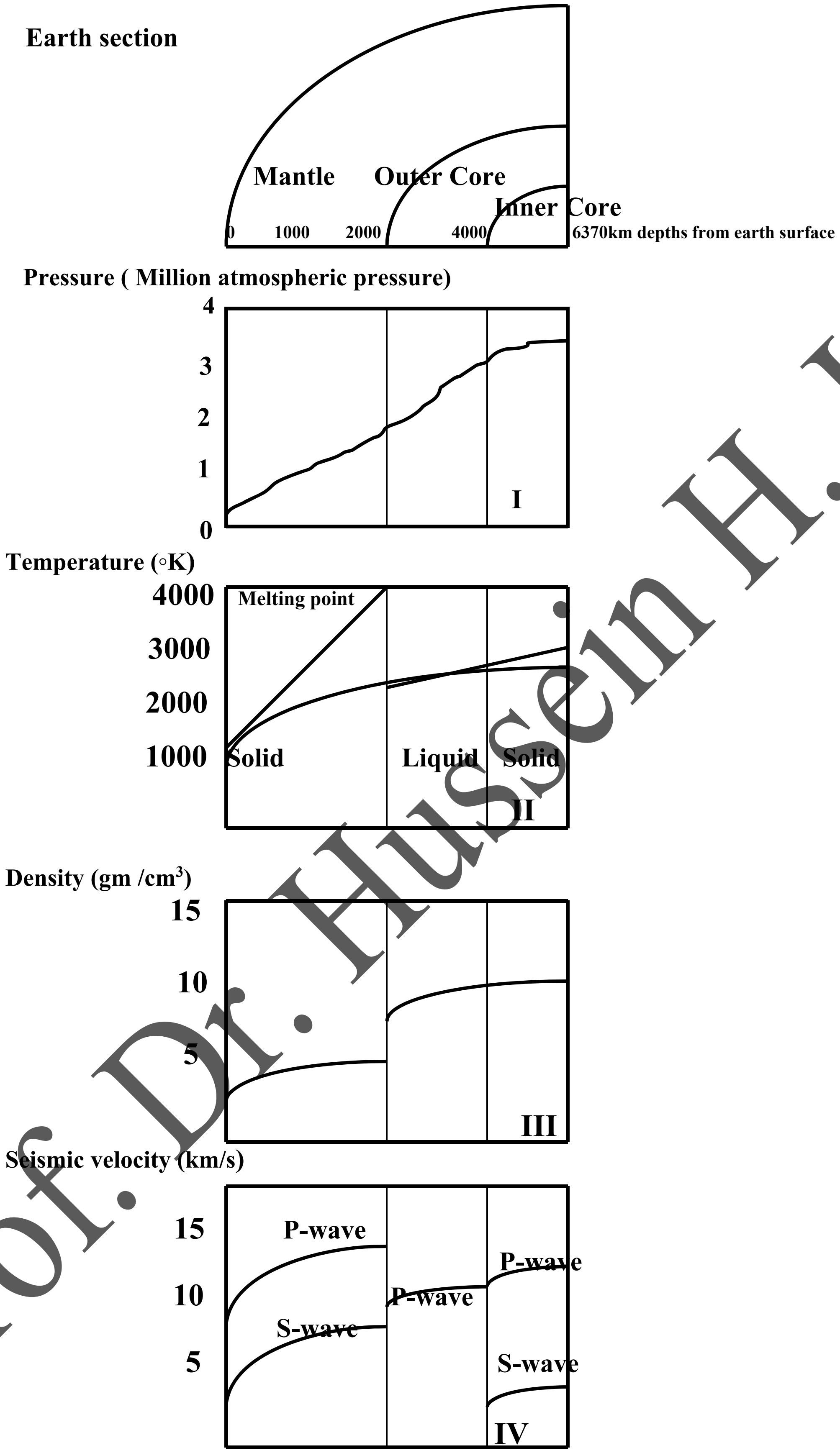


Fig.(2.3). Variations of some physical conditions.

2.4 The Rock Cycle

By studying the rock cycle (Fig. 2.4) we may ascertain the origin of the three basic rock types and get some information about the role of various geologic processes in transforming one rock type into another. The concept of the rock cycle, which may be considered as a basic outline of physical geology, was initially proposed by ***"James Hutton"***. Rocks are classified according to their origin into igneous, sedimentary and metamorphic rocks.

The first rock type, igneous rock, originates when molten material called ***magma*** cools and solidifies. This process called ***crystallization*** may occur either beneath the earth s surface or following eruption at the surface. Initially, or shortly after forming, the earth’s outer shell is believed to have been molten. As this molten material gradually cooled and crystallized, it generated a primitive crust that consisted entirely of igneous rocks.

If igneous rocks are exposed at the surface of the earth will undergo ***weathering*** in which effects of atmosphere disintegrate and decompose slowly rocks. The materials that result will be picked up, transported, and deposited by any of a number of erosional agents, gravity, running water, glaciers, wind, or waves. Once these particles and dissolved substances called ***sediment*** are deposited usually as horizontal beds in the ocean, they will undergo ***lithification,*** a term meaning conversion into rock. Sediment is lithified when compacted by weight of overlying layers or when cemented as percolating water fills the pores with mineral matter. If the resulting ***sedimentary rock*** is buried deep within the earth or involved in the dynamics of mountain building, it will be subjected to great pressure and heat. The sedimentary rock will react to the changing environment and turn into the third type ***metamorphic rock***. When metamorphic rock is subjected to still greater heat and pressure, it will melt, creating magma, which will eventually solidify as igneous rock.

The full cycle does not always take place, for example, igneous rock rather than being exposed to weathering and erosion at the earth s surface, may be subjected to the heat and pressure found far below and change to metamorphic rock. On the other hand, metamorphic rock and sedimentary rocks, as well as sediment, may be exposed at the surface and turned into new raw materials for sedimentary rock.

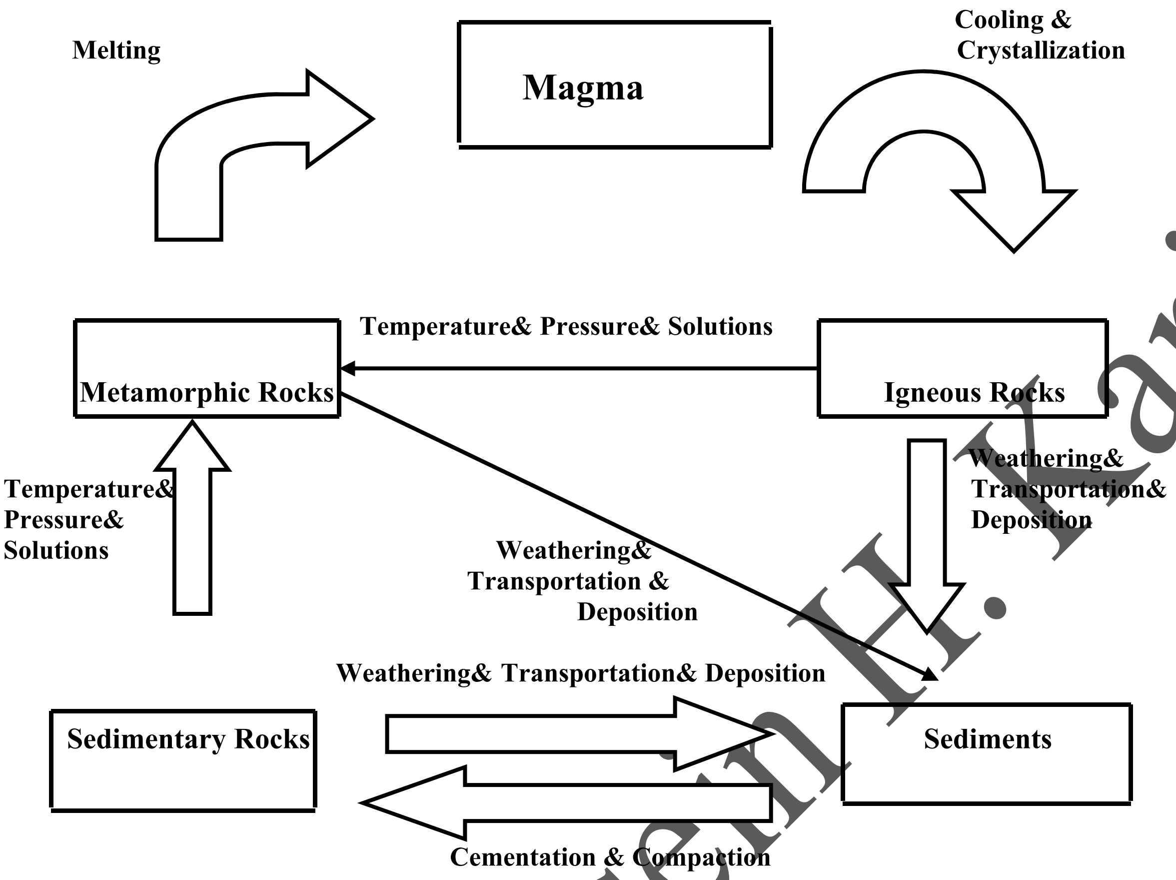


Fig. (2.4). Rocks cycle (or Geologic cycle).

REVIEW QUESTIONS

2.1 List the main discontinuities within earth envelopes with their depths.

2.2 What evidence do we have that the earth's outer core is molten?

2.3 Contrast between:
a- Sial and Sima
b- Inner and outer core

2.4 Describe the chemical (mineral) makeup of the following:
a- Continental crust
b- Oceanic crust
c- Mantle
d- Core

2.5 Show the variations of the below physical conditions with depth from earth surface:
a- Pressure,
b-Temperature,
c- Density, and
d- Seismic velocities

2.6 Explain the concept of the rock cycle.

2.7 Explain the main constituents of solid earth envelopes.

2.8 What are the main minerals forming earth crust showing their percentages?

2.9 Does the full geologic cycle always take place ? Why ?

3. Minerals

3.1 Introduction

A ***mineral*** is a naturally occurring inorganic substance which has a definite physical, chemical composition, and definite crystalline structure (crystal form) normally uniform throughout its volume. In contrast, ***rocks*** are collections of one or more minerals. In order to understand how rocks vary in composition and properties, it is necessary to know the variety of minerals that commonly occur in them, and to identify a rock it is necessary to know which minerals are present in it. A mineral is considered to be the unit of rock composition for example quartz, calcite, diamond (C) sulphur (S).

3.2 Formation of Minerals

The minerals are formed by different methods**:**

1- Crystallization from magma**:** Crystallization is the transformation from liquid state to solid state due to cooling process and forming ***crystal***.
2- Precipitation from chemical solutions by means of chemical reactions or microfauna.
3- Minerals may be formed directly from gases by densification.
4- New minerals may be formed by the effect of pressure and temperature as minerals forming metamorphic rocks.

3.3 Classification of Minerals

The best classification of minerals is that depending on chemical composition which classifies minerals into two main categories: silicate minerals, non silicate minerals, but others classify them in three groups in which clay minerals represent the third one for its importance.

1- Silicate Minerals:

These are the main category representing rock forming minerals and subdivided into many groups according to their chemical composition (ratio Si/O) as listed in the below table (Table 3.1).

Table (3.1). Silicate minerals groups.

Group	**Si**	**O**	**Example**
a- Quartz	1	2	Quartz
b- Feldspar	3	8	Orthoclase & Plagioclase
c- Amphibole	4	11	Hornblende
d- Pyroxene	1	3	Augite
e- Olivine	1	4	Olivine
f- Mica	2	5	Biotite & Muscovite

2- Non silicate Minerals

They are often called ore - forming minerals and they are subdivided into the following groups:

1- Native Elements: Sulphur (S), diamond (C) .
2- Oxides: Hematite (Fe_2O_3), magnetite (Fe_3O_4).
3- Carbonates: Cacite ($CaCO_3$), dolomite [$Ca,Mg\ (CO_3)_2$].
4- Sulphates: Anhydrite ($CaSO_4$), gypsum ($CaSO_4 .2H_2O$) .
5- Sulphides: Galena (PbS), pyrite (FeS_2) .
6- Phosphates: Apatite [$Ca,F(PO_4)_3$] .
7- Florides: Fluorite (CaF_2).
8- Chlorides: Halite (NaCl).

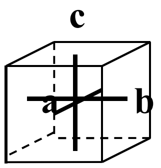
3- Clay Minerals

They are hydrous alumina silicates originate as products of the chemical weathering of the other silicate minerals. Clay minerals are also important rock forming minerals since they constitute shales and make up a large percentage of the soil. Because of the importance of soil in agriculture and as a supporting material for buildings, clay minerals are extremely important to for geologists and civil engineers.

3.4 Crystal Forms of Minerals

A mineral specimen can be an object of beauty in those occasional circumstances where it forms a single crystal or cluster of crystals. In such an environment, it develops a regular pattern of faces and angles between the faces, which is characteristic of a particular mineral. The study of this regularity of form, and of the internal structure of the mineral to which it is related, is called ***crystallography***. A ***crystal*** is defined as a polyhedral form bounded by plane surfaces (faces) that reflects the orderly internal arrangement of atoms with a specific crystal form and constant angles and ordered in special systems. Crystals are classified into seven systems according to their degree of symmetry and to the geometrical relationships of their crystallographic axes (their relative lengths and the angles between them).

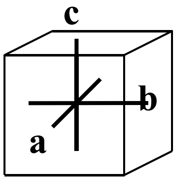
1- Cubic (or Isometric) System: It consists three mutually perpendicular axes, all of the same length ($\mathbf{a_1=a_2=a_3}$). Four fold axis of symmetry around $\mathbf{a_1}$, $\mathbf{a_2}$, and $\mathbf{a_3}$. Mineral examples, galena (PbS), fluorite, magnetite and halite (Fig.3.1).



$\mathbf{a = b = c}$; $a \perp b \perp c$

Fig. (3.1). A cubic system.

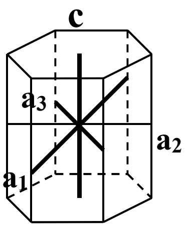
2- Tetragonal System: It consists three mutually perpendicular axes, two of the same length (**$a_1=a_2$**) and a third (**c**) of a length not equal to the other two. Four fold axis of symmetry around (**c**). Mineral examples, zircon and casseterite (Fig.3.2).



$a = b \neq c$; $a \perp b \perp c$

Fig. (3.2). A tetragonal system.

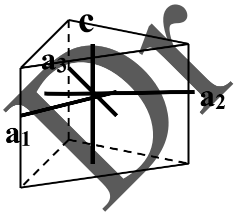
3- Hexagonal System: It consists four axes, three horizontal axes of the same length (**$a_1=a_2=a_3$**) and intersecting at 120°. The fourth axis (**c**) is perpendicular to the other three. Six fold axis of symmetry around **c**. Mineral examples, apatite (Fig.3.3).



$a1 = a2 = a3 \neq c$; $a1, a2, a3 \perp c$

Fig. (3.3). A hexagonal system.

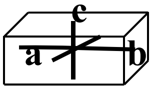
4- Trigonal System: It consists four axes, three horizontal axes of the same length (**$a_1=a_2=a_3$**) and intersecting at 120°. The fourth axis (**c**) is perpendicular to the other three. Three fold axis of symmetry around **c**. Mineral examples, calcite, quartz, and corundum (Fig.3.4).



$a1 = a2 = a3 \neq c$; $a1, a2, a3 \perp c$

Fig. (3.4). A trigonal system.

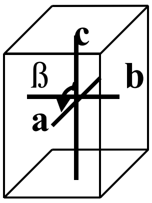
5- Orthorhombic System: It consists three mutually perpendicular axes of different lengths (**$a \neq b \neq c$**). Two fold axis of symmetry around **a**, **b** and **c**. Mineral examples, olivine and topaz (Fig. 3.5).



$a \neq b \neq c$; $a \perp b \perp c$

Fig. (3.5). An orthorhombic system.

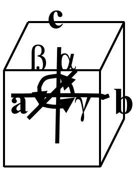
6- Monoclinic System: It consists three unequal axes, two mutually perpendicular axes (**b** and **c**) of any length. A third axis (**a**) at an oblique angle (**ß**) to the plane of the other two. Two fold axis of symmetry around **b**. Mineral examples, orthoclase, gypsum and hornblende (Fig. 3.6).



$$\mathbf{a \neq b \neq c \quad ; \quad c \perp b}$$

Fig. (3.6). A monoclinic system.

7- Triclinic System: It consists three axes at oblique angles (α, ß, and γ), all of unequal length. No rotational symmetry. Mineral examples, plagioclase (microcline and albite) (Fig. 3.7).



$$\mathbf{a \neq b \neq c}$$

Fig. (3.7). A triclinic system.

3.5 Identification of Minerals

For a civil engineer, a study of rock–forming minerals is important to enable him to distinguish the various rock types. So minerals may be distinguished from one another by their distinctive physical properties. There are two fundamental characteristics of a mineral that together distinguish it from all other minerals are its chemical composition and its crystal structure. No two minerals are identical in both respects, though they may be the same in one. For example, diamond and graphite (the "lead" in a lead pencil) are chemically the same-both are made up of pure carbon. Their physical properties, however, are vastly different because of the differences in their internal crystalline structure. Both mineral's composition and crystal structure can usually be determined only by using sophisticated laboratory equipment. There are other important properties that are used to identify minerals in hand specimens without special equipments those are as follows:

1- Color

The ***color*** of a mineral is that seen on its surface by the naked eye. It may depend on the impurities present in light-colored minerals, and one mineral specimen may even show gradation of color or different colors. For these reasons, color is usually a general rather than specific guide to which mineral is present.

Iridescence is a play of colors characteristic of certain minerals. The very common mineral quartz, for instance, is colorless in its pure form. However, quartz also occurs in other colors, among them pink, golden yellow, smoky brown, purple and milky white. Clearly, quartz cannot always recognized by its color, or lack of it.

2- Streak

The ***streak*** is the color of the powdered mineral. This is most readily seen by scraping the mineral across a plate of unglazed hard porcelain and observing the color of any mark left. It is a diagnostic property of many ore minerals. For example, the lead ore, galena, has a metallic grey color but a black streak.

3- Lustre

Light is reflected from the surface of a mineral, the amount of light depending on physical qualities of the surface (such as its smoothness and transparency). This property is called the ***lustre*** of the mineral, and is described according to the degree of brightness from ***"splendent"*** to ***"dull"***. The terms to describe lustre are given in Table 3.2.

Table (3.2). Descriptive terms for the lustre of minerals.

1- Metallic	like polished metal (galena, magnetite)
2- Submetallic	less brilliant (Cinnabar)
3- Nonmetallic	
Adamantine	like diamond lustre
Vitreous	like broken glass
Resinous	oily sheen
Silky	like strands of fibre parallel to surface
Pearly	like mica and talc lustres
Greasy & Waxy	
Dull & Earthy	like kaolin lustre

4- Cleavage

Cleavage is the way the crystals break up when struck. Most minerals can be cleaved along certain specific crystallographic directions which are related to planes of weakness in the atomic structure of the mineral . These ***cleavage directions*** are usually, but not always, parallel to one of the crystal faces. Some minerals, such as quartz and garnet, possess no cleavages, whereas others may have one (micas), two (pyroxenes and amphiboles), three (galena) or four (fluorite). When a cleavage is poorly developed it is called a ***parting***.

A surface formed by breaking the mineral along a direction which is not a cleavage is called a ***fracture*** and is usually more irregular than a cleavage plane. A fracture may also occur, for example, in a specimen which is either an aggregate of tiny crystals or glassy (that is, non-crystalline). A curved, rippled fracture is termed ***conchoidal*** (shell-like).

5- Hardness

Hardness, the ability to resist scratching, is another easily measured physical property that can help to identify a mineral, although it usually does not uniquely identify the mineral. The relative hardness (***H***) of two minerals is defined by scratching each with the other and seeing which one is gouged. It is defined by an arbitrary scale of ten standard minerals, arranged in ***Mohs' scale of hardness*****,** and numbered in degrees of increasing hardness from 1 to 10 (Table 3.3). The hardnesses of items commonly available are also shown, and these may be used to assess hardness within the lower part of the range. The only common mineral that has a hardness greater than 7 is garnet. Most others are semiprecious or precious stones.

Table (3.3). Mohs' scale of hardness.

1	**Talc**	Hydrated magnesium silicate
2	**Gypsum**	Hydrated calcium sulphate
3	**Calcite**	Calcium carbonate
4	**Fluorspar**	Fluoride
5	**Apatite**	Calcium phosphate
6	**Feldspar**	Alkali silicate scratched by a file
7	**Quartz**	Silica scratches glass
8	**Topaz**	Aluminum silicate
9	**Corundum**	Alumina
10	**Diamond**	Carbon

6- Transparency

Transparency is a measure of how clearly an object can be seen through a crystal. The different degrees of transparency are given in Table 3.4.

Table (3.4). Degrees of transparency.

1- Transparent: An object is seen clearly through the crystal, like window glass.
2- Subtransparent: An object is seen with difficulty.
3- Translucent: An object cannot be seen, but light is transmitted through the crystal.
4- Subtranslucent: Light is transmitted only by the edges of a crystal.
5- Opaque: No light is transmitted; this includes all metallic.

7- Specific Gravity

The ***specific gravity*** or ***density*** of a mineral can be measured easily in a laboratory, provided the crystal is not too small. The specific gravity (sp. gr.) is given by the relation:

Specific gravity $= W_1 / (W_1 - W_2)$

where W_1 is the weight of the mineral grain in air, and W_2 is the weight in water. A steelyard apparatus such as the Walker Balance is commonly used. In the field such a means of precision is not available, and the specific gravity of a mineral is estimated as low, medium or high by the examiner. It is important to know which minerals have comparable specific gravities:

(a) **Low Specific Gravity Minerals:** include silicates, carbonates, sulphates and halides, with specific gravities ranging between 2.2 and 4.0.

(b) Medium Specific Gravity Minerals: include metallic ores such as sulphides and oxides, with specific gravities between 4.5 and 7.5.

(c) High Specific Gravity Minerals: include native metallic elements such as pure copper, gold and silver; but these are rare minerals and are very unlikely to be encountered.

8- Other Properties

Taste, ***feel***, ***optical properties*** and ***magnetic properties*** are diagnostic of a few minerals. ***Reaction with acids***, when a drop of cold 10% dilute hydrochloric acid is put on certain minerals, a reaction takes place. In calcite ($CaCO_3$), bubbles of carbon dioxide make the acid froth, and in some sulphide ores, hydrogen sulphide is produced. ***Tenacity*** is a measure of how the mineral deforms when it is crushed or bent as shown in Table 3.5.

Table (3.5). Descriptive terms for the tenacity of minerals.

Brittle	Shatters easily.
Flexible	Can be bent , but will not return to original position after pressure is released.
Elastic	Can be bent , and returns to original position after pressure is released.
Malleable	Can be hammered into thin sheets.
Sectile	Can be cut by a knife e ductile can be drawn into thin wires.
Ductile	Can be drawn into thin wires.

Some minerals often occur together whereas others are never found together because they are unstable as a chemical mixture and would react to produce another mineral. Nearly all identification of minerals in hand specimens in the field is made with the proviso that the specimen being examined is not a rare mineral but is one of a dozen or so common, rock-forming minerals, or one of a couple of dozen minerals commonly found in the sheet-like veins that cut rocks.

The difference between common quartz and one particular rare mineral in a hand specimen is insignificant and easily missed, but mistakes of identification are presumably as rare as the mineral. The same limits of resolution. Using such simple techniques mean also that only in favorable circumstances is it possible to identify, for example, which variety of feldspar is present in a fine - grained rock as distinct from identifying feldspar.

Three or four properties are usually sufficient for a positive identification of a particular mineral and there is little point in determining the others. For example, a mineral with a metallic lustre, three cleavages all at right angles, a grey color and a black streak is almost certainly the common lead ore, galena.

REVIW QUESTIONS

3.1 Although all minerals have an orderly internal arrangement of atoms (crystalline form) , most mineral samples do not demonstrate their crystal form. Why?

3.2 Distinguish between calcite and dolomite?

3.3 Explain the difference between the terms silicon and silicates.

3.4 Why might it be difficult to identify a mineral by its color?

3.5 What two properties uniquely define a particular mineral?

3.6 If you found a glassy - appearing mineral while rock hunting and had hopes that it was a diamond , what simple test might help you make a determination?

3.7 Gold has a specific gravity of almost 20 . If a 25 liter pail of water weighs about 25 kgm, how much would a 25 liter pail of gold weigh?

3.8 What do ferromagnesian minerals have in common ? List examples of ferromagnesian minerals.

3.9 What do muscovite and biotite have in common? How do they differ?

3.10 Distinguish between orthoclase feldspar and plagioclase feldspar?

3.11 Each of the following statements describes a silicate mineral or mineral group. In each case, provide the appropriate name.
a- The most common member of the amphibole group.
b- The most common non ferromagnesian member of the mica family.
c- The only silicate mineral made entirely of silicon and oxygen.
d- A high-temperature silicate with a name that is based on its color.
e- Characterized by striations.
f- Originates as a product of chemical weathering .

3.12 Define a crystal. What is its main components ? According to what properties , crystals have been classified?

3.13 What is the main unit of rock composition?

4. Rocks

4.1 The Nature of Rocks

Rocks are aggregates of one or more mineral. The nature and properties of a rock are determined by the minerals in it (particularly those ***essential minerals*** which individually make up more than 95% of its volume) and by the manner in which the minerals are arranged relative to each other (that is, the texture of the rock). Weathering, of course, will affect the engineering properties of a rock, and this is dealt with in detail in Chapter 5. An individual rock type or specimen is always described in terms of its mineral composition and its texture, and both are used in the classification of rocks. According to their manner of formation, or genetic classification, rocks are of three main types:

1- I**gneous rocks** are formed from magma, which has originated well below the surface, has ascended towards the surface, and has crystallized as solid rock either on the surface or deep within the earth's crust as its temperature fell.
2- **Sedimentary rocks** are formed by the accumulation and compaction of; (a) fragments from pre-existing rocks which have been disintegrated by erosion ; (b) organic debris such as shell fragments or dead plants; or (c) material dissolved in surface waters (rivers, oceans, etc.) or ground water, which is precipitated in conditions of oversaturation.
3- **Metamorphic rocks** are formed from pre-existing rocks of any type, which have been subjected to increases of temperature **(*T*)** or pressure **(*P*)** or both, such that the rocks undergo change. This change results in the metamorphic rock being different from the original parental material in appearance, texture and mineral composition.

4.2 Igneous Rocks

Igneous rocks represent about 25% of earth surface rocks but 95% of earth crust rocks. Those rocks formed by cooling and solidification of hot molten mineral matter, known ***Magma*** below the surface of the earth. If this material comes to the earth surface, it is termed as ***lava*** which is similar to magma except that most of the gaseous component has escaped. The process by which crystals are formed after cooling is called ***crystallization***. The rocks which result when lava solidifies are classified as ***extrusive, or volcanic***. The magma is not able to reach the surface eventually crystallizes at depth and producing ***intrusive, or plutonic*** rocks.

4.2.1 Formation of Igneous Rocks

Extrusive Igneous Rocks

The rocks which result when lava solidifies by rapid cooling at the surface are classified as ***extrusive (volcanic) igneous rocks***. When cooling occurs quite rapidly, the outcome is the formation of a solid mass formed of very small crystals. The resulting rocks fine grained (***aphanitic texture***), such as basalt, andesite, rhyolite and dacite rocks. Conversely, most, but not all, fine-grained igneous rocks are extrusive. When crystals have no enough time to grow a microcrystalline texture is produced. Sometimes the magma has chilled so quickly that crystals have failed to form. The rock is then a natural glass, and is described as having a ***glassy texture*** such as obsidian and pumice rocks, this texture occurs most commonly in acid extrusive rocks. ***Vesicular texture*** is characterized by the presence of vesicles-tabular, or spherical cavities in the rock and occurs most commonly in extrusive rocks in which the gases dissolved in magma under the high pressures.

Plutonic Igneous Rocks

When a magma cools very slowly, it results in the formation of rather large crystals , so igneous rocks produced in this manner are termed ***intrusive (plutonic) igneous rocks***, typically at depths of a few kilometres within the earth. When large masses of magma solidify far below the surface, they form igneous rocks that exhibit a coarse–grained texture described as ***phaneritic***. These coarse–grained rocks are roughly equal in size and large enough so that the individual minerals can be identified with the unaided eye, which is sometimes called ***granular texture*** such as granite, granodiorite, diorite, peridotite and gabbro.

When the resulting rock has large crystals embedded in a matrix of smaller crystals, is said to have a ***porphyritic texture*** exists where larger and smaller crystals are both present in the same rock (Figs. 4.1 and 4.2). The larger crystals in such a rock are referred to as ***phenocrysts***, while the matrix of smaller crystals is called ***groundmass***. A rock which has such a texture is called ***porphyry*** which is found most commonly in extrusive rocks, but is also sufficiently common in some intrusive rocks (hypabyssal rocks). For example, in quartz porphyry the most common phenocryst is quartz. The texture is frequently produced when a rock has cooled in two or more stages, and crystals from the first stage gain a head start in growth over the later-stage crystals of the matrix.

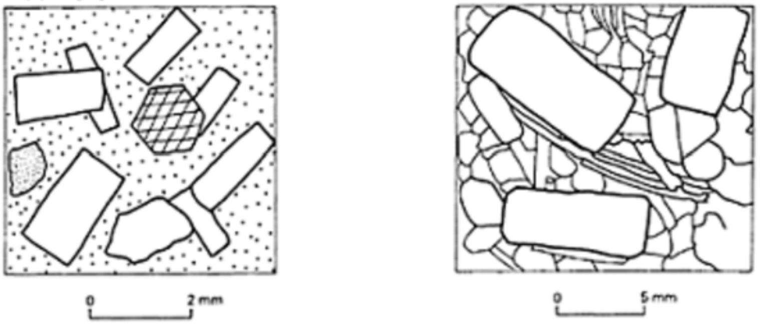


Fig. (4.1). Porphyritic rocks.

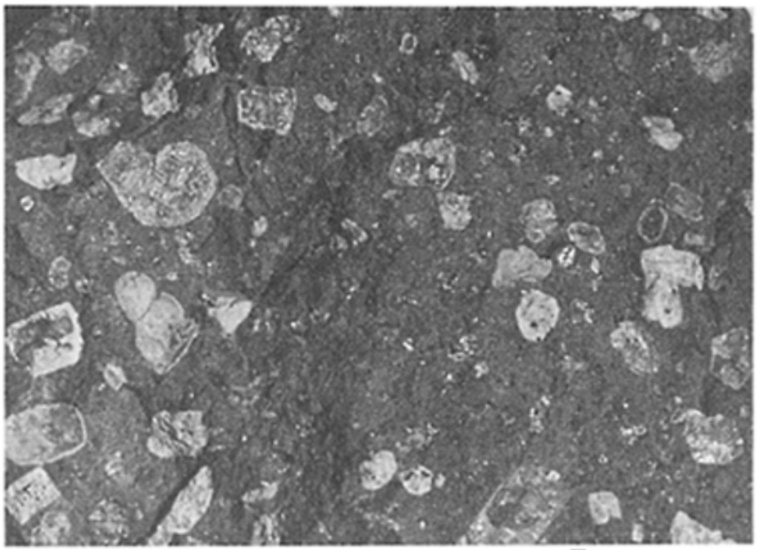


Fig. (4.2). Porphyritic texture in fine-grained basalt.

4.2.2 Igneous Structures and Forms

Extrusive Rocks

Extrusive rocks are formed when molten rock (***magma***) reaches the surface, along either wide vertical fissures or pipe-like openings in the earth's crust. Fissure openings may vary from a fraction of a kilometer to several kilometers in length. Huge outpourings of magma can be emitted from such fissures. Depending on their composition, ***lavas*** may have a rough broken surface (***scoriaceous lava***) or a smooth wrinkled surface (***ropy lava***) when extruded. Other forms are ***blocky*** (irregular form), ***columnar joints*** resulted from contraction due to cooling, and ***pillows*** when lava flows under water.

Intrusive (Plutonic) Rocks

Intrusive Igneous structures and forms are classified into two main categories with respect to depth:

a- Hyabyssal Rocks: Rocks that are formed at an intermediate depths between volcanic and plutonic of fine-, medium-grained size which include. The common hypabyssal intrusions (Fig. 4.3) are sheet-like in form, with widths usually between 1 and 70 m. They are labelled according to whether or not they conform to the structure of the strata in which they are emplaced:

1- Sills: A **concordant hypabyssal intrusion** injected along the layering in the country rocks is called a ***sill***. Most sills are subhorizontal, so the terms are often used loosely with this relative orientation in mind.

2- Dykes: A **discordant hypabyssal intrusion** cutting steeply across the layering is called a ***dyke*** and most dykes are near-vertical.

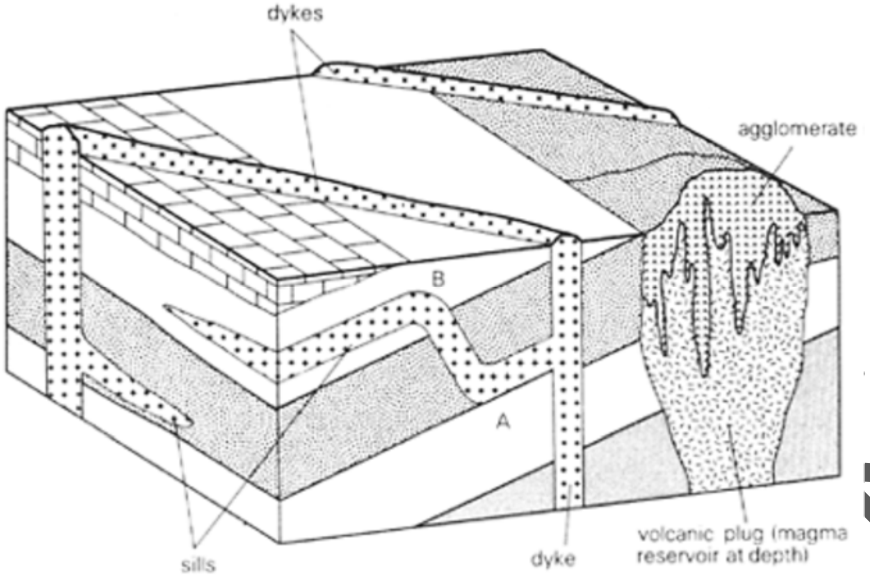


Fig. (4.3). **The common types of hypabyssal intrusion: a volcanic plug, a sill and a dyke are shown in sections and on the surface.**

b- Structures and Forms of Intrusive (Plutonic) Rocks at greater depths:

These structures and forms are formed at greater depths under high temperature and pressure resulted in coarse-grained rocks, some of these structures are:

1- **Laccolith:** The smallest intrusions are often mushroom-shaped with a flat base and an upwards bulging roof, similar to sills but with restricted movement of magma because the that generates laccolith magma is believed to be quite viscous.
2- **Phacolith:** Other forms of structures those are undulated parallel to fold layers with lens-shaped mass.
3- **Lopolith :** Sheets of this type are a few kilometers thick, often down-warping the underlying original rocks because of the weight of magma involved.
4- **Batholith :** The major plutonic intrusion which is a great body , always formed from acid magma, and it is characteristic of late igneous activity in mobile belts. For its largeness, different believes have been introduced for its origin (Fig. 4.4).

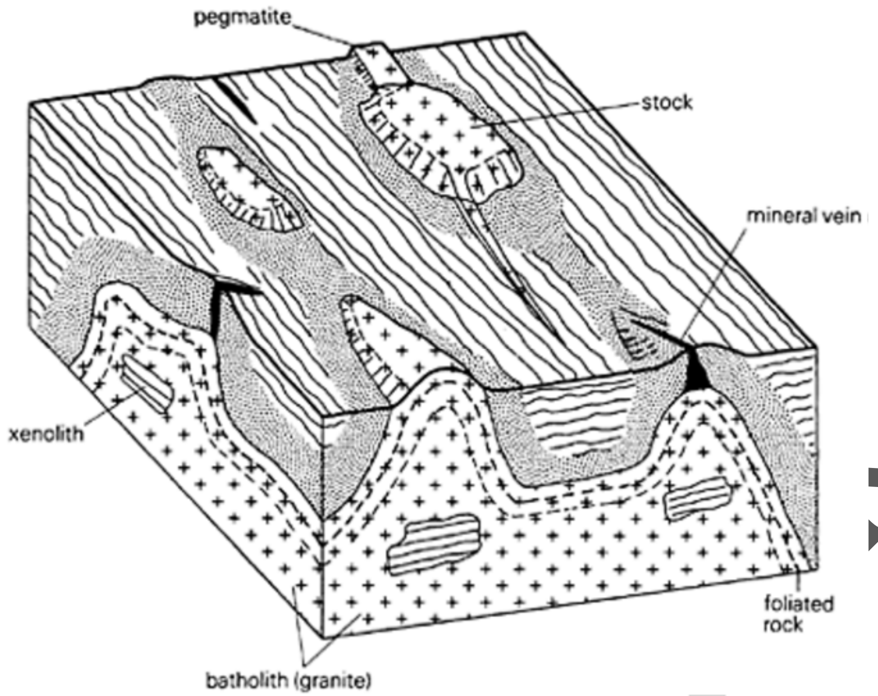


Fig. (4.4). The granite of the batholith has been emplaced in country rocks.

4.2.3 Classification of Igneous Rocks

Igneous rocks are classified according to the mode of formation, texture and composition.

1- Mode of Formation:

a- Volcanic: fine-grained, aphanitic, e.g basalt, dacite, andesite, rhyolite.

b- Plutonic: coarse-grained, phaneritic, e.g. diorite, granite, gabbro.

c- Porphyritic: e.g. porphyritic andesite.

d- Glassy: e.g. obsidian.

2- Textural Subdivision:

A variety of textures may occur in igneous rocks. Each reflects the physical conditions under which the rock formed. With few exceptions, igneous rocks are composed of interlocking crystals (only a few of which display a perfect crystal form), and are said to have a ***crystalline texture***. The next most important textural feature is the size of the individual crystals, and this is used as a criterion, together with mineral composition, in the most common and simplest classification of igneous rocks. Generally speaking, crystal size is usually related to how long it has taken the magma-to solidify completely, and thus how much time individual crystals have had to grow. In ***fine-grained rocks*****,** crystals are on average less than

1 mm across, in ***medium-grained rocks*** they are between 1 and 5 mm across, and in ***coarse-grained rocks*** they are over 5 mm across. Tables 4.1 and 4.2 shows the main textures and the relation of grain size and cooling rate of igneous rocks respectively.

Table (4.1). The main textures of igneous rocks.

a- Fine-grained	Aphanitic, also known volcanic.
b- Medium-grained	also known hyabyssal.
c- Coarse-grained	Phaneritic, also known plutonic.
d- Porphyritic	
e- Vesicular	
f- Glassy	

Table (4.2). The relation of grain size and cooling rate of igneous rocks.

Grain Size	**Dimension**	**Cooling Rate**
Very coarse-grained	> 30 mm	Very slow
Coarse-grained	> 5 mm	Slow
Medium	1-5 mm	Medium
Fine	< 1 mm	Rapid
Very fine	Not seen with eyes	Very rapid
Glassy	Noncrystalline	Intensively very rapid
Vesicular	Noncrystalline	Vesicles

3- Mineral Composition

Igneous rocks are subdivided according to their mineral composition into (Fig. 4.5 and Table 4.3):

a- Acidic: Sialic-silica and alumina, light color, its mineral composition is mainly feldspar (orthoclase, plagioclase) and quartz, e.g. granite rock.

b- Intermediate: It lies between acidic and basic, intermediate in color , its composition is mainly feldspar and little quartz, e.g. andesite rock.

c- Basic: Simatic-silica and magnesia, dark color, its mineral composition is mainly biotite, pyroxene, amphiboles, e.g. gabbro rock.

d- Ultra-Basic: Ferromagnesian minerals are predominant without quartz, e.g. olivinite rock.

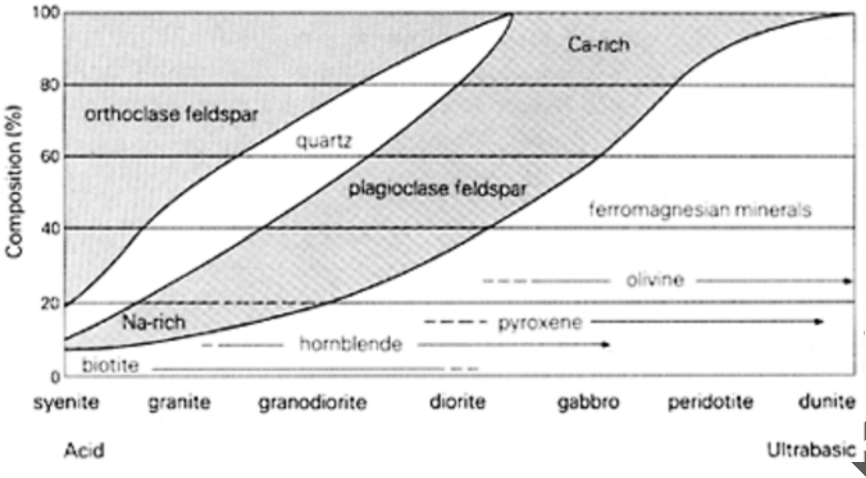
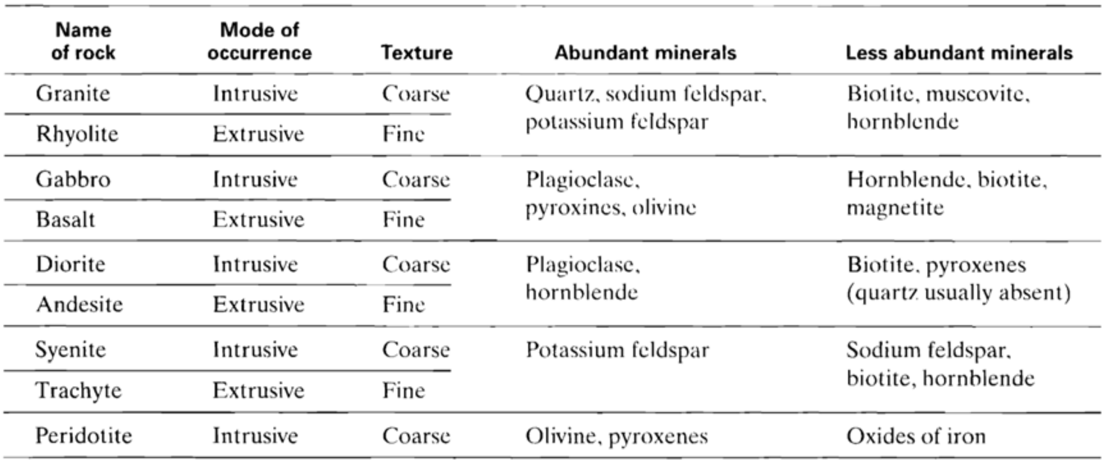


Fig. (4.5). Igneous rock composition, based on the proportion of each mineral present.

Table (4.3). Composition of some igneous rocks.



Name of rock	Mode of occurrence	Texture	Abundant minerals	Less abundant minerals
Granite	Intrusive	Coarse	Quartz, sodium feldspar, potassium feldspar	Biotite, muscovite, hornblende
Rhyolite	Extrusive	Fine		
Gabbro	Intrusive	Coarse	Plagioclase, pyroxines, olivine	Hornblende, biotite, magnetite
Basalt	Extrusive	Fine		
Diorite	Intrusive	Coarse	Plagioclase, hornblende	Biotite, pyroxenes (quartz usually absent)
Andesite	Extrusive	Fine		
Syenite	Intrusive	Coarse	Potassium feldspar	Sodium feldspar, biotite, hornblende
Trachyte	Extrusive	Fine		
Peridotite	Intrusive	Coarse	Olivine, pyroxenes	Oxides of iron

4.3 Sedimentary Rocks

Sedimentary rocks are formed from the solid debris and the dissolved mineral matter produced by the mechanical and chemical breakdown of pre-existing rocks, or in some cases from the skeletal material of dead plants and animals. The processes involved in the disintegration of rocks by weathering and erosion, and the transport of these products to the place where they are deposited**.**

Sediments and sedimentary rocks are of great importance for engineers since the deposits ("soils" to an engineer) which have recently formed, or are forming, blanket most of the solid rocks of the earth, and are the natural material encountered and dealt with in nearly every shallow excavation. These modern deposits are also relevant in discussing the solid sedimentary rocks, which have been produced from similar accumulations in the geological past. The sediment has been transformed into solid rock by compaction as it was buried and compressed by subsequent deposits. Sedimentary rocks form about 75% of the earth surface (upper part of earth crust down to about 8 km.).

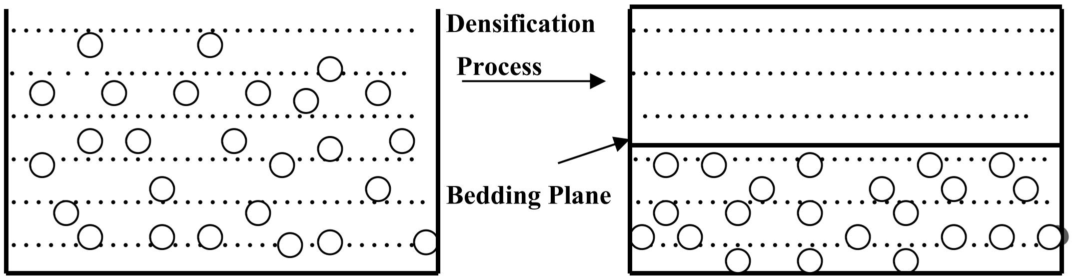
4.3.1 Major Processes for Sedimentary Rocks Formation

The main processes are:

1- **Weathering and Erosion**: Weathering is the disintegration and decomposition of rock at or near the surface of the earth. Whereas erosion is the incorporation and transportation of material by mobile agent, usually water, wind or ice.
2- **Transportation**: It includes the mobile agents mentioned above .
3- **Deposition:** It is the site of deposition of the materials in a sedimentary basin. By compaction and cementation, these sediments will transform to solid rocks.

Briefly, the primary requirements for the formation of sedimentary rocks are: ***source of sediments*** and ***site of deposition*** (Fig. 4.6).

Since these are deposits, they possess ***bedding*** characteristics (***layers***). Rocks with different composition, grain size, color, etc are called ***strata***, while the boundary separating two different strata is called ***stratification***. The process by which the sediments transforms to sedimentary rocks is called ***lithification***. Each group of sedimentary rocks deposited in the same geologic time is called ***formation***.



a- Sediments b- Sedimentary rocks

Fig. (4.6) . Formation of sedimentary rocks.

4.3.2 General Properties of Sedimentary Rocks

1- They possess bedding planes or stratification which indicate non deposition period.
2- They contain fossils (plant or animal remains).
3- They are often porous which is important for the presence of oil, gas and underground water.
4- The surface of the grains are smooth due to weathering and erosion processes.
5- They often contain fractures, cavities, channels and faults which affect engineering projects.

4.3.3 Factors Affecting Variety of Sedimentary Rocks

Three main factors are affecting the variety of sedimentary rocks, these are:

1- **Type of the original rock material**: Where chemical weathering of calcareous rocks produces calcareous rocks too, and physical weathering of sandstone produces sandstone too. Whereas, chemical and physical weathering of igneous and metamorphic rocks produce different rocks .
2- **Type of transportation**: Different deposits formed with different agent of transportation (wind, water and glaciers).
3- **Environment of deposition**: Different environments cause different sedimentations. Thus it may be described according to the type of environment in which it accumulated:
   a- Continental deposits: If it were laid down on land or in a lake by rivers, ice or wind.. If the agents are rivers ***(fluviatile deposits)***, wind ***(Aeolian deposits)*** and glaciers ***(glacial deposits)***.
   b- Transitional (Intermediate) deposits: If it were laid down in an estuary or delta deposits formed in delta (***deltaic***), and deposits formed in estuaries of rivers ***(estuarine)***.

c- Marine deposits: These deposits formed along coastlines, shores, continental shelves and deposits formed in the abyssal areas of the deep oceans (under greater depth of water) are ***abyssal deposits*** (Fig. 4.7).

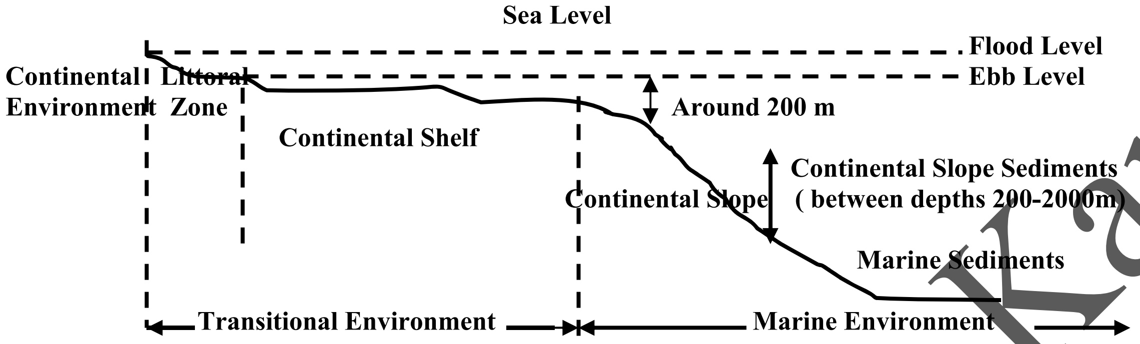


Fig. (4.7). Depositional Environments of sedimentary rocks.

4.3.4 Textures and Kinds of Deposition of Sedimentary Rocks

The material from which sedimentary deposits are formed derived in the following ways:

1- **Mechanical Deposits**: Formed from the accumulation of pebbles, sand, clay and fragments of other rocks such as sandstones, shales and conglomerates. The texture of these deposits is called ***clastic*** (***detrital***) texture.
2- **Chemical and Organic Deposits**: Formed from minerals were once dissolved in water and then precipitated out, such as limestones, salt, gypsum and anhydrites. The texture is called ***crystalline***. Whereas, organic deposits are formed from plant and animal remains, such as certain limestones and coal.

The main elements of texture of sedimentary rocks are: ***grains***, ***matrix*** and ***cementing material*** between grains and matrix.

4.3.5 Sedimentary Rock Structures

The occurrence of sedimentary structures indicates some variation in composition or texture of sedimentary rock layers in response to changes in the environmental conditions in which the particular sediment was laid down. The most common sedimentary structures are:

1- **Stratification or Bedding Planes:** The sedimentary layers are called strata or beds which are the single most characteristic feature of sedimentary rocks. The thickness of layers ranges from microscopically thin to tens of meters thick . Separating the strata are bedding planes which are flat surfaces along which rocks tend to separate . Changes in the grain size or in the composition of the sediment being deposited can create bedding planes. Pauses in deposition can also lead to layering.

2- **Mud Cracks**: They indicate that the sediment in which they formed was alternately wet and dry. When exposed to air , wet mud dries out and shrinks, producing cracks.

3- **Ripple Marks**: They are characteristic of sediments deposited where was a forward and backward movement of water, such as one might find in a standing body of water affected by wave action. Current ripple marks indicate that the sediment was deposited by running water or by wind. Such feature give clues to past environments. It may produce by streams or tidal currents flowing across a sandy bottom or by wind blowing over a sand dune. Some ripple marks can be used to determine the direction of movement of ancient currents and winds(Fig. 4.8).

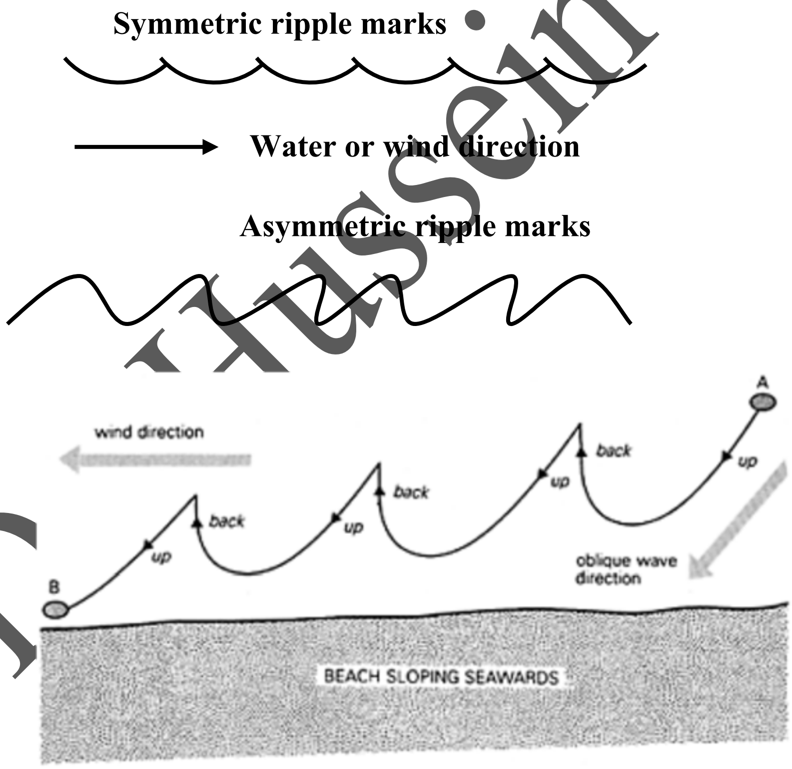


Fig. (4.8). Ripple marks.

4- **Cross Bedding (Current Bedding):** It is characteristically laid down at an angle to the horizontal, such as on the lee side of a sand dune, and while the major bedding is horizontal, there is a subset that is at an angle. Sometimes when a bed of sedimentary rock is examined, we can see layers inclined at a steep angle to the horizontal. Such layering is termed cross bedding and is most characteristic of river deltas and sand dunes. It has been laid down in shallow water or deposited as dunes by the action of wind. Successive minor layers are formed as sand grains settle in the very slow moving, deeper water at the downstream end of a sandbank or delta, and the sandbank grows in that direction. Each layer slopes down stream and is initially ***S-shaped***; however, erosion of the top of the sand bank by the stream leaves the minor layering still curving tangentially towards the major bedding plane at its base, but truncated sharply at its junction with the upper bedding plane (Fig. 4.9). Because of its mode of origin, it is sometimes referred to as ***current bedding***.

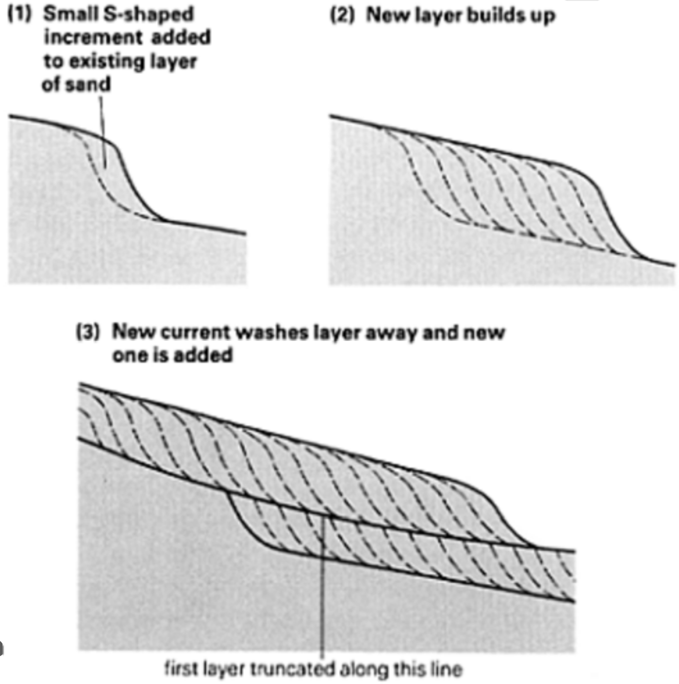


Fig. (4.9). Formation of current bedding.

5- **Graded bedding**: In graded bedding**,** a sediment containing a wide range of grain sizes is sorted vertically such that there is a continuous gradation from coarse particles at the bottom of the sedimentary layer to fine grains at the top (Fig. 4.10). Certain thick sedimentary sequences are characterized by a rhythmic alternation of thin sandstones and shales. The sandstones (or ***greywackes***) show graded bedding. These are believed to have been deposited by ***turbidity currents*****,** probably flowing off ocean shelf areas into deep water carrying a slurry of sand-laden muddy water, which forms ***turbidites***.

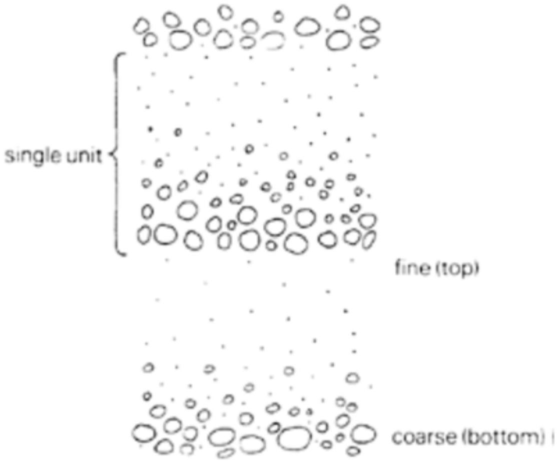


Fig. (4.10). Sequence of graded beds.

4.3.6 Classification of Sedimentary Rocks

The major groups of sedimentary rocks are:

a- Clastic Sedimentary Rocks (sometimes referred to as ***Mechanical*** or ***Detrital*** or ***Terrigenous rocks***)

They are formed from minerals or rock fragments derived from the break-down of pre-existing rocks. The deposits of gravel, sand, silt, and clay formed by weathering may become compacted by overburden pressure and cemented by agents like iron oxide, calcite, dolomite, and quartz. Cementing agents are generally carried in solution by groundwater. They fill the spaces between particles and form sedimentary rock. Conglomerate, breccia, sandstone, mudstone, and shale are some rocks example of the detrital type. For civil engineer, clastic sedimentary rocks are classified, with respect to their grain size, according to Atterberg's scale as shown in table (4.4).

Table (4.4). Clastic sedimentary rocks classification according to Atterberg's scale.

Sediment		**Grain Size**
Gravel		> 2 mm
Sand	Coarse	2 – 0.6 mm
	Medium	0.6 – 0.2 mm
	Fine	0.2 – 0.06 mm
Silt	Coarse	0.06 – 0.02 mm
	Medium	0.02 – 0.006 mm
	Fine	0.006 – 0.002 mm
Clay		< 0.002 mm

b- Chemical Sedimentary Rocks

They are formed by chemical processes from the precipitation of salts dissolved in water. Limestones and dolomites, which are chemical sedimentary rocks consisting of more than 50% carbonate, and can include chemical, clastic and biological material. Limestone ($CaCO_3$) is formed mostly of calcium carbonate that originates from calcite deposited either by organisms or by an inorganic process. Dolomite is calcium magnesium carbonate [$CaMg(CO_3)_2$] that is formed either by the chemical deposition of mixed carbonates or by the reaction of magnesium in water with limestone originates from calcite. Other examples of this type are: evaporites (gypsum and anhydrite) result from the precipitation of soluble $CaSO_4$ because of evaporation of ocean water, while rock salt (NaCl) is another example of an evaporite that originates from the salt deposits of seawater; siliceous deposits (chert and flint).

c- Organic Sedimentary Rocks

They are formed from the skeletal remains of plants and animals and include coal and oil. Some examples for this type are: calcareous (corals, shells), siliceous (diatoms), carbonaceous (forest trees), and phosphatic (animal bones). Besides, limestone may be originated from calcite deposited by organisms .

4.4 Metamorphic Rocks

If a rock is subjected to increased temperature or pressure, or both, to such a degree that it is altered by recrystallization, then a new rock with a new texture and possibly a new mineral composition is produced. Rocks formed in this way belong to the third major category of rocks, the ***metamorphic rocks.*** 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.

4.4.1 Agents of Metamorphism

The agents 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 temperature averages about 30ºC 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 200–750ºC or more near molten materials.

2- Pressure as a 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 a 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 the formation of completely new minerals.

4.4.2 Types of Metamorphism

Metamorphism most often occurs in three settings:

1- Thermal (or Contact) Metamorphism

In ***thermal metamorphism***, increased temperature is the dominant agent producing change, and the degree of recrystallization 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 igneous intrusions and have been baked and altered by the hot magma. Some examples limestone is metamorphosed to marble and sandstone 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 one 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.

4.4.3 The Bases of 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 rock 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. Metamorphic rocks are subdivided into two main types; ***foliated*** texture (***oriented*** and ***banded***) and ***non- foliated*** texture (***crystalline*** and ***granular***).

4.4.4 Classification of Metamorphic Rocks

1- Foliated Metamorphic Rocks

Those rocks which possesses a definite banded structure. These rocks have texture which may cause them to break along parallel surfaces. 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 conditions 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 mudstones are transformed into slates and phyllites by low-grade metamorphism. At medium-grade metamorphism, rocks are transformed to schists. And at high-grade metamorphism, all rocks are transformed to gneiss as shown in Figure 4.11.

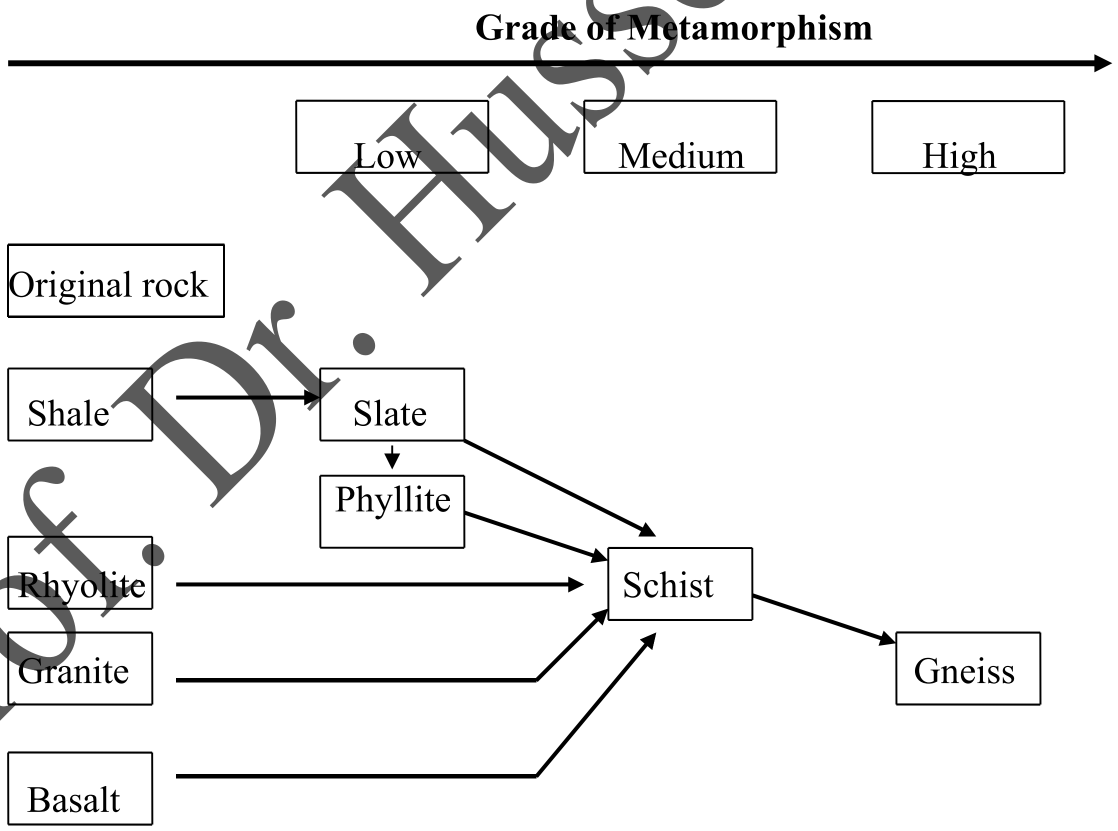


Fig. (4.11). The effect of grade of metamorphism on original rocks.

2- Non-Foliated Metamorphic 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 sandstones (Fig. 4.12).

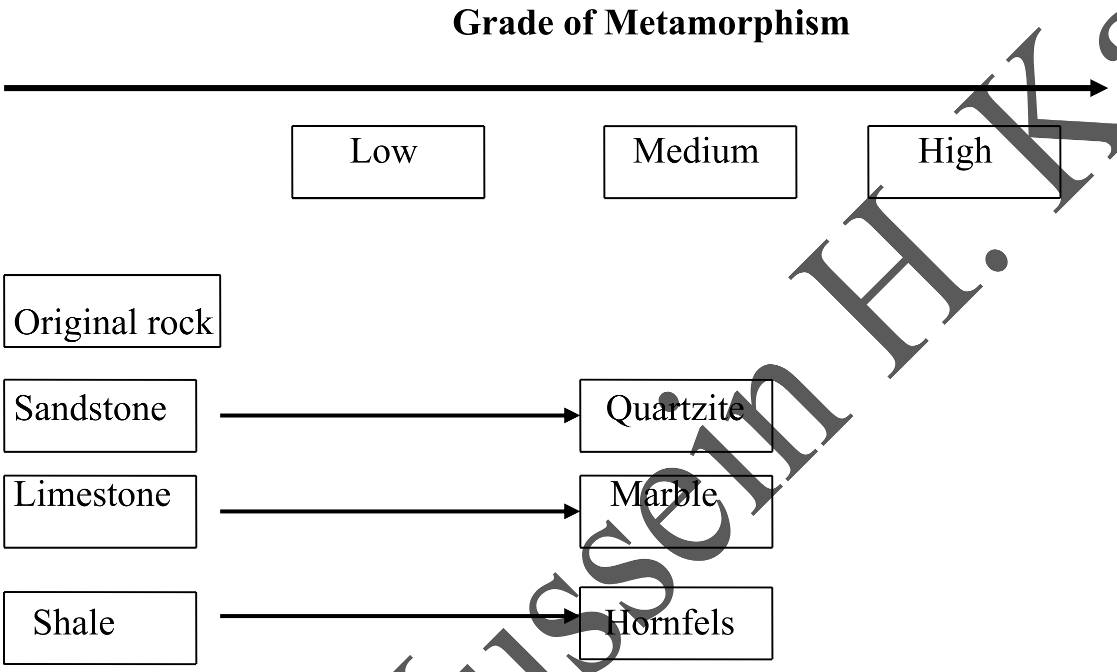


Fig. (4.12). The effect of grade of metamorphism on original rocks.

REVIEW QUESTIONS

4.1 Define the term ***"rock"***.

4.2 How does lava differ from magma?

4.3 In addition to the rate of cooling , what other factors influence crystallization?

4.4 The classification of igneous rocks is based largely upon two criteria. Name these criteria.

4.5 The statements that follow relate to terms describing igneous rock textures. For each statement, identify the appropriate term.
a- Openings produced by escaping gases.
b- Obsidian exhibits this texture.
c- A matrix of fine crystals surrounding phenocrysts.
d- A texture characterized by two distinctively different crystal sizes.
e- Coarse-grained, with crystals of roughly equal size.

4.6 What does a porphyritic texture indicate about an igneous rock?

4.7 How are granite and rhyolite different? In what way are they similar?

4.8 Compare and contrast each of the following pairs of rocks:
a- Granite and diorite.
b- Basalt and gabbro.
c- Andesite and rhyolite.

4.9 How do tuff and volcanic breccia differ from other igneous rocks such as granite and basalt?

4.10 What is igneous rocks ? How do volcanic and plutonic rocks differ in texture? Why?

4.11 Why might a laccolith be detected at the earth's surface before being exposed by erosion?

4.12 What is the largest of all intrusive igneous bodies? Is it tabular or massive? Concordant or discordant?

4.13 Granite and basalt are exposed at the surface in a hot, wet region.

a- Which type of weathering will predominate?
b- Which of the rocks will weather most rapidly? Why?

4.14 How does the volume of sedimentary rocks in the earth's crust compare with the volume of igneous rocks in the crust ? Are sedimentary rocks evenly distributed throughout the crust?

4.15 What minerals are most common in detrital sedimentary rocks? Why are these minerals so abundant?

4.16 What is the primary basis for distinguishing among various detrital sedimentary rocks?

4.17 The term "clay" can be used in two different ways. Describe the two meanings of this term?

4.18 Distinguish between conglomerate and breccia.

4.19 Distinguish between the two categories of chemical sedimentary rocks.

4.20 What are evaporate deposits? Name a rock that is an evaporate.

4.21 Compaction is an important lithification process with which sediment size?

4.22 List three common cements for sedimentary rocks. How might each be identified?

4.23 What is the primary basis for distinguishing among different chemical sedimentary rocks?

4.24 Distinguish between clastic and nonclastic textures. What type of texture is common to all detrital sedimentary rocks?

4.25 What is the single most characteristic feature of sedimentary rocks?

4.26 What is metamorphism? What are the agents of change?

4.27 What is foliation?

4.28 List some changes that might occur to a rock in response to metamorphic processes.

4.29 Slate and phyllite resemble each other. How might you distinguish one from the other?

4.30 Each of the following statements describes one or more characteristics of a particular metamorphic rock. For each statement, name the metamorphic rock that is being described.

a- Calcite-rich and nonfoliated.
b- Foliated and composed mainly of granular materials.
c- Represents a grade of metamorphism between slate and schist.
d- Very fine- grained and foliated; excellent rock cleavage.
e- Foliated and composed of more than 50 percent platy minerals.
f- Often composed of alternating bands of light and dark silicate minerals.
g- Hard, nonfoliated rock resulting from contact metamorphism.

4.31 Distinguish between contact metamorphism and regional metamorphism. Which creates the greatest quantity of metamorphic rock?

4.32 What feature would make schist and gneiss easily distinguishable from quartzite and marble?

4.33 Briefly describe the textural and mineralogical differences among slate, mica schist, and gneiss. Which one of these rocks represents the highest degree of metamorphism?

4.34 Are gneisses associated with high-grade or low-grade metamorphism?

4.35 Which type of rocks is important for civil engineer? Why ?

4.36 What we call each group of sedimentary rocks deposited in the same geologic time?

5. Weathering, Erosion and Soil Formation

5.1 Introduction

Rock decay with little or no transport of the products is termed ***weathering***; and when the rock or its products is simultaneously removed, this is termed ***erosion*.** Soil erosion is caused by the action of water and wind. Surface runoff and wind together carry away loosened soil. Soil is produced by weathering, a term including variety of chemical, physical, and biological processes acting to break down rocks. It may be formed directly from bedrock, or from further breakdown of transported sediment such as glacial till. The relative importance of the different kinds of weathering processes is largely determined by climate. Climate, topography the composition of the material from which the soil is formed, the activity of organisms, the time govern a soil's final composition. Weathering and erosion of rocks give rise a serious problems especially in areas subject to construction or strip mining and hence rock properties influence the stability of construction projects.

5.2 Weathering

Three processes of weathering and erosion at, and near, the surface transform solid rock into unconsolidated rock waste. These are as follows:

a- The physical or mechanical disintegration of a rock mass at the surface as water, wind, ice and the rock fragments carried by them buffet or press against it, or force it apart;

b- Chemical reactions between the original minerals of the rock, the near-surface water and the oxygen of the atmosphere to produce new minerals which are stable under the conditions at the earth's surface and remove other more soluble constituents;

c- Biological activity, which produces organic acids, thus adding to the chemical reactions, and which may also be an agent assisting mechanical disintegration.

5.2.1 Types of Weathering

I- Physical (Mechanical) Weathering

Mechanical weathering leads to a physical disaggregation of the original rock mass into smaller particles. This can be caused by any one of several natural agents. Some of these agents of mechanical weathering are discussed later.

a- Freezing of water within a crack produces an expanded wedge of ice which forces the walls of the crack apart. If the process is repeated by alternate thawing and freezing, fragments from the outer surface of the rock eventually break off to form loose scree.

b- The same mechanical effect may be produced locally in the rock by chemical reactions between certain minerals and water that has penetrated along cracks. The hydration of these minerals produces a local increase in volume, and local pressure causes disintegration of the rock. Similarly, entry of water into the minute void spaces in rocks may allow salts to crystallize there and press against the walls of the void, thus weakening the rock.

c- Other processes involving the action of water in its various forms include erosion by ice, wave action at coasts, river erosion, and slopes being made unstable by the presence of water in the ground.

d- Expansion and contraction of the outer skin of a rock mass as it was heated by the sun and cooled at night were formerly thought to be an important agent of weathering, but careful modern studies show that this process (called ***exfoliation***) requires water to be present for it to work.

e- Crystal growth and salts.

f- Granular disintegration.

g- Near-surface rock removal.

II- Chemical Weathering

Chemical weathering is the reaction of the original minerals of the rock with water, oxygen and organic acids at the Earth's surface so that they are broken down chemically with the production and release of new products, some of which are soluble. water is by far the most important agent of chemical weathering. Chemical weathering involves the complex processes that alter the internal structures of minerals by removing and/or adding elements. Chemical weathering of common rock-forming minerals produces clay minerals. The process of chemical weathering involves the simultaneous operation within one rock which includes the main group:

1- Hydrolysis: The chemical union of water and a mineral is known as hydrolysis. In hydrolysis, ions derived from one mineral react with the H or OH ions of the water to produce a different mineral. A good example of hydrolysis is the chemical weathering of K-feldspar ($KAlSi_3O_8$). Two substances are important, carbon dioxide (CO_2) and water (H_2O). The atmosphere and soil contain CO_2, which units with rainwater to form carbonic acid (H_2CO_3). If K-feldspar comes in contact with H_2CO_3, a mineral will form as follows:

$$\mathbf{2KAlSi_3O_8 + H_2CO_3 + H_2O \longrightarrow Al_2Si_2O_5(OH)_4 + K_2CO_3 + 4SiO_2}$$

K-feldspar   Carbonic Acid   Water   Clay mineral   Potassium Carbonate   Silica

Thus hydrolysis is an extremely important weathering process because it acts on feldspars and ferromagnesian minerals.

2- Solutions: The primary erosional work carried out by surface and groundwater is that of dissolving rocks. Since soluble rocks (rock salt, gypsum and limestone),especially limestone, underlie millions of square kilometers of the earth's surface, it is here that groundwater carries on its rather unique and important role as an erosional agent. Therefore, when groundwater comes in contact with limestone, the carbonic acid reacts with calcite in the rocks to form calcium bicarbonate, a soluble material that is then carried away in solution. By this way stalactites and stalagmites are formed. ***Stalactites*** found in caverns hang from the ceiling of the cavern and form where water seeps through cracks above. Features that form on the floor of a cavern and reach upward toward the ceiling called ***stalagmites***.

3- Hydration: It is a reaction in which water combines with a rock constituent producing a mineral that has hydroxyl groups (OH) in its structure, the hydroxyl group coming from the water. An example is the transformation of anhydrite to gypsum.

$$\mathbf{CaSO_4 + H_2O \longrightarrow CaSO_4 . 2H_2O}$$

Anhydrite Gypsum

4- Carbonation: It is a reaction involving carbonic acid and limestone. Carbonic acid is formed when carbon dioxide from the atmosphere dissolves in water. It can then react with limestone (calcite) to produce soluble calcium or sodium bicarbonate.

5- Oxidation: In this process, atmospheric oxygen combines with a mineral to produce an oxide. The process is important in the weathering of minerals with high iron content, such as olivine, pyroxene and amphiboles. The iron in silicate mineral units oxygen to form hematite (Fe_2O_3) or limonite ($Fe_2O_3.3H_2O$) rock constituent, and in two typical reactions produces new iron-bearing minerals.

6- Reduction: takes place in environments deficient in oxygen, and the products of such a reaction contain relatively little oxygen. For example, in oxidizing conditions organic matter is converted to carbon dioxide (CO_2), but in reducing conditions methane (CH_4) is often formed.

7- Dissolution: Water is one of the most effective solvents. Some rock types can be completely dissolved and leached away by water. Rock salt (NaCl) is the best known example. Gypsum ($CaSO_4.H_2O$) is less soluble than rock salt but also easily dissolved by surface water. Sulphates, nitrates, chlorides and carbonates are highly soluble, though the calcium-magnesium carbonate (dolomite) is much less soluble than calcite. Most oxides are unstable and react with water to produce hydrated minerals, but titanium oxides are stable and occur in soils in very small amounts. Sulphides are unstable and may give rise to small quantities of sulphuric acid.

III- Biological Weathering

Weathering is also accomplished by the activities of organisms, including plants, burrowing animals and humas. Plant root widens cracks and contributes to the rock breakdown. Burrowing animals further breakdown rock by moving fresh material to the surface, where physical and chemical processes can more effectively attack it.

5.2.2 Rate of Weathering

The rate of weathering depends on many factors. The particle size influences the rate of weathering. The mineral make-up of a rock is also a very important factor. Climatic factors, temperature and moisture, are of primary significance to the rate of weathering. The sum of these factors determine the type and rate of rock weathering for a given region. Thus silicate minerals are highly resistant to both physical and chemical weathering. Feldspar minerals are less, whereas the ferromagnesian minerals are the least resistant to weathering.

5.2.3 Depth of Weathering

The depth of weathering depends very much on local climatic effects (such as ground temperature), soil/rock type and time. Freezing slows down some processes of soil formation; thus arctic soils are poorly developed. In contrast, the process of soil formation may penetrate to great depths in the tropics. The mean temperature at the surface over periods of years rather than the daily or even annual variations is the factor that controls ground temperature below the top few meters. Rocks and soils are very poor conductors of heat, and annual fluctuations cancel out at depths of about 3 m. Daily variations have no effect below the top 1 m. The relative importance of reactions involving water depends both on rainfall and on the temperature of the water.

In tropical rainforests have heavy rainfall, which in turn yields a profusion of vegetable matter and saturation of all cracks and other voids in the rocks and soils to within a short distance of the surface. In limestone country, closed depressions are sometimes seen. These form as a result of the solution of limestone by meteoric waters that carve out underground caverns, the roofs of which collapse. This landscape feature is known as ***karst topography***.

5.3 Soil and Soil Formation

Geologists and engineers give different meanings to the word ***"soil".*** Geologists use the term to refer to any rock waste, produced by the disintegration of rocks at the surf ace by weathering processes, which has formed ***in situ***, include all unconsolidated material overlying bedrock. These untransported surface deposits are called ***sedentry*** or ***residual deposits***. In contrast, engineers use the term ***"soil"*** more widely and more loosely, to describe any superficial or surficial deposit which can be excavated without blasting. This definition covers ***transported sediments*** as well as residual deposits. Thus, engineers would regard ***"soil"*** as including water-transported sediments **(*alluvium*),** wind transported material (***dunes*** and ***loess***), sediment transported by glaciers or their meltwaters (***till*** or ***glacial drift***) and material moved downhill by gravity **(*colluvium*)**. Some rocks (such as London Clay) may even be thought of as "soil" by the engineer, since these can be easily excavated.

5.3.1 Types of Soils

5.3.1.1 Residual Soils

These are untransported soils produced by the disintegration of rocks at the surface by weathering processes, which has formed ***in situ***. These soils are more common than transported soils. Their Thickness depends upon climate, original rock type and time. The main characteristics of this soil are:

1- The mineralogical composition is closely related to the original bed rock beneath soil.
2- The soil grains are irregular, sharp and lack roundness.
3- The soil contains fragments of the original rock.
4- The soil thickness depends upon the depth of weathering, climatic conditions, nature of rocks, topography and time.
5- The presence of complete soil profile reflecting the gradual change from original rock at the bottom to topsoil at the surface (Fig. 5.1). Since soil-forming processes operate from the surface downward, variation in composition, texture, structure and color gradually evolve at varying depths . These vertical differences, which usually become more pronounced as time passes , divide the soil into zones or layers known as ***horizons.*** Such a vertical section through all of the soil horizons constitutes the ***soil profile***. Four basic horizons are identified and from top to bottom are designated as **O, A, B** and **C**. The boundaries between soil horizons may be very sharp, or the horizons may blend gradually from one to another. The three upper layers may be further subdivided.

O-horizon: It consists largely of organic material, and the upper portion is primarily loose leaves and other organic material. While its lower portion is made up of partly decomposed organic matter (***humus***) .

A-horizon: It consists mainly of mineral matter, yet biological activity is high and humus is generally present up to 30% in some instances.

B-horizon: Immediately below the A-horizon is the B-horizon or subsoil. Much of the fine clay material removed from the A-horizon by water percolation downward is deposited in the B-horizon which is often referred to as the ***zone of accumulation*** since the B-horizon has an intermediate position in the soil profile.

C-horizon: A layer characterized by partially altered parent material and little if any organic matter. It may be considered a ***transitional zone.***

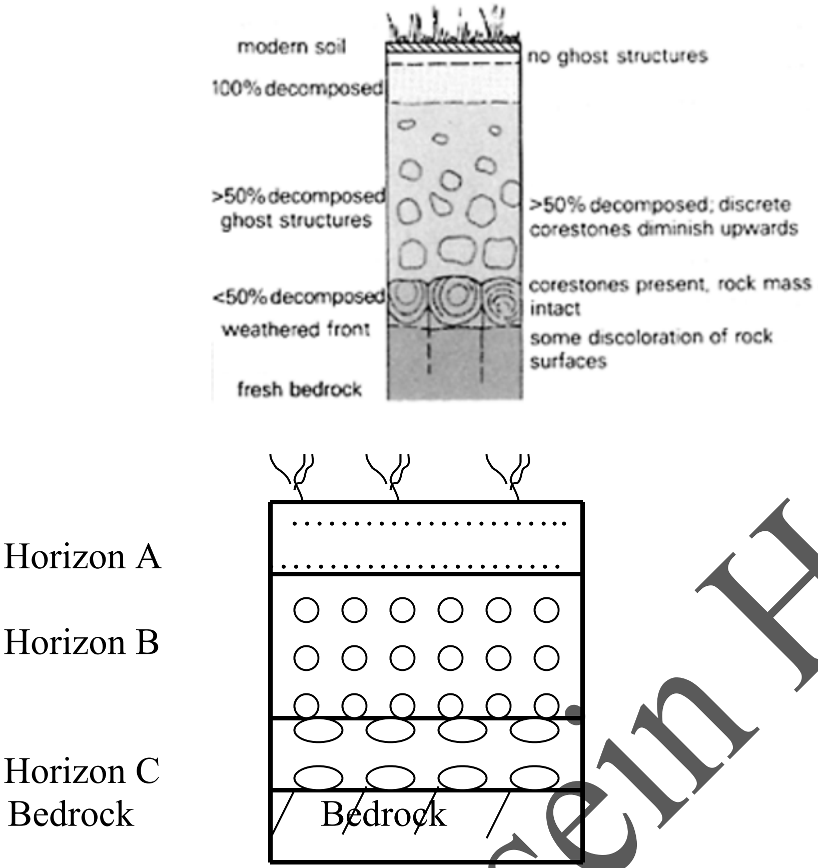


Fig. (5.1). Typical residual deposits overlying bedrock .

Classification of residual soils

Most modern soils develop profiles related to the climatic and vegetational zones in which they occur, and for this reason they are referred to as ***zonal soils***. Of these soils are :

1- **Laterites**: Red soils rich in iron oxides and alumina abundant in the hot wet climates of the tropics (i.e. high temperatures and heavy rainfall).
2- **Brown Soils**: A mixture of clay and sand rich in iron oxides and organic matter (humus).
3- Black Soils: Dark colored soils rich in organic matter.

5.3.1.2 Transported Soils

Transported soils are those developed on unconsolidated sediment that are formed of rock debris which has been carried by some natural agent from where it was formed by weathering and erosion to where it now occurs. These soils are characterized by the absence of the **C**-horizon, also **A** and **B**-horizons are not well pronounced particularly when the soil is recent. But they usually become more pronounced with time as the accumulation of fine clay particles derived from the **A**-horizon to the **B**-horizon (Fig. 5.2) .

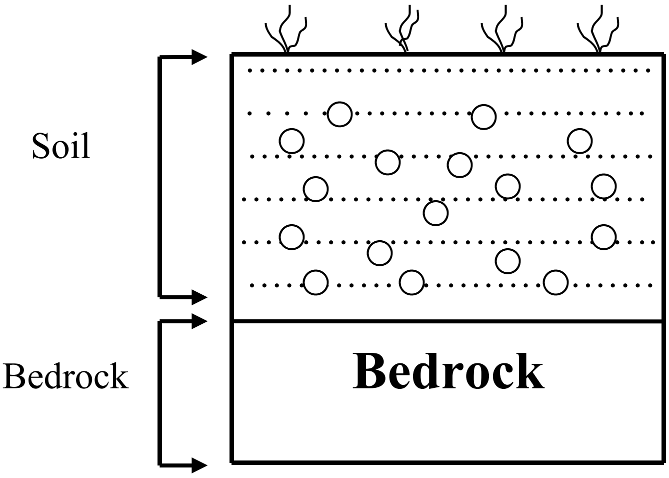


Fig. (5.2) . Soil profile for transported soils.

Classification of Transported Soils

Transported soils are described and classified most simply by reference to the agent that moved them and the local conditions that controlled their deposition. Four important agents of erosion and transport (wind, rivers, the sea at coasts, and glaciers) and the deposits associated with them are described in the following sections.

1- Aeolian (Windborne) Deposits (Soils): A strong wind blowing across rock debris or soil can lift and carry fine material as dust, and can move the larger sand grains by rolling them and making them bounce across the surface. This windborne movement of material occurs in areas with little or no vegetation and is typical of hot desert regions. Wind both transports and sorts the material.

a- **Loess**: The finer, yellow-colored, silt-sized fraction (0.002-0.006 mm) is carried in suspension by the wind, and may travel great distances before it is eventually deposited as loess. They are composed mainly of quartz, feldspar, calcite and mica with a smaller fraction of other stable minerals such as iron oxides. Clay minerals are virtually absent.

b- Sand dunes: The coarser rounded material that remains forms sand dunes, composed mainly quartz with little feldspar. They are found in desert regions, although the process also operates in some coastal areas.

2- Glacial (Iceborne) Deposits (Soils): Erosion by ice, and deposition of superficial deposits from it, are processes limited geographically at the present day to arctic regions and to very high mountains. Wide areas of the present temperate zones, including most of Britain, were affected by glaciation and many of their superficial deposits were laid down directly from ice, or from melt waters flowing from the glaciers.

3- Aqueous Deposits (Soils): The soils that are deposited by running or slack water which are considered the most important soils in Iraq.

a- Continental Deposits : They include fresh water deposits :

I- Alluvial (Riverborne) Deposits (Soils): They include river, flood plain and deltaic soils . Lateral erosion by a river into its banks eventually produces a valley which is much wider than its course. Erosion at one point is matched by deposition at another and a wide valley is eventually filled with ***alluvial deposits*** . These include cross - bedded and evenly bedded sands, silts and gravels, plus spreads of fine silt and clay across the flat ***flood plain*** at the sides of a river.

II- Lacustrine Soils: They composed mainly of silts deposited in lakes and reservoirs .

b- Marine Deposits: They include all sediments of the marine and transitional environments.

5.3.2 Mineral Composition of Soils

Of the hundred or so elements known, only eight are abundant at the earth's surface. These, in decreasing order of abundance, are oxygen (O), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), sodium (Na), potassium (K) and magnesium (Mg). The common rock-forming minerals are formed mainly of combinations of these important elements, and most of them are silicates.

Clay Minerals and their Groups

Clay is a term used to describe a variety of complex minerals which, like the micas, have a sheet structure. The clay minerals are generally very fine grained and can only be studied microscopically**. *Clay minerals*** form mainly by the alteration of other silicate minerals, by the action of weathering. The specific type of clay formed depends upon the composition of the original mineral undergoing alteration and the surface conditions where weathering is taking place. The change is not usually a direct or simple one. Other alteration products which are not strictly clays may be formed as intermediate stages of the weathering process, and one clay mineral may be transformed into another more stable one as conditions change. For example, secondary chlorite, formed by hydrothermal alteration of primary ferromagnesian minerals, will itself alter readily to clay during the weathering process. Thus, clay minerals make up a large percentage of the surface soil. Because of the importance of soil in agriculture, and because of its role as a supporting material for buildings, clay minerals are extremely important to humans.

It needs to be well recognized that the presence of clay minerals in a soil aggregate has a great influence on the engineering properties of the soil as a whole. When moisture is present, the engineering behavior of a soil will change greatly as the percentage of clay mineral content increases. For all practical purposes, when the clay content is about 50% or more, the sand and silt particles float in a clay matrix, and the clay minerals primarily dictate the engineering properties of the soil. Thus, soil forming minerals play an important role in its engineering properties. Sandy soils appear less problems compared with clayey soils as the former contains mainly quartz mineral which is more resistant to both physical and chemical weathering. Structurally, clayey soils are more complex than sandy soils as the anomalous properties of clays mainly belong to their mineralogical composition which are mainly formed by chemical weathering of the original minerals forming ***hydrous aluminum silicates*** or clay minerals.

Structurally, clay minerals are complex hydrous aluminum silicates composed of two basic units:
(l) silica tetrahedron and; (2) alumina octahedron unit (gibbsite $Al(OH)_3$).
Each tetrahedron unit consists of four oxygen atoms surrounding a silicon atom. The combination of tetrahedral silica units gives a silica sheet. The octahedral units consist of six hydroxyls surrounding an aluminum atom, and the combination of the octahedral aluminum hydroxyl units gives an octahedral sheet. This is also called a gibbsite sheet.

a- Kaolinite Group: $Al_2Si_2O_5(OH)_4$

Of the three important clay minerals, ***kaolinite*** consists of repeating layers of elemental silica-gibbsite sheets in a 1: 1 lattice since one silica layer is coupled with one gibbsite layer (G) as shown in Figure 5.3a. Two units are held together by attraction (van der Waals' forces). The layers are held together by hydrogen bonding. It is less soluble in water. The weak forms contain a layer of water between silica-gibbsite sheets. Thus, from engineering point of view, it is considered to have the lowest liquid- plastic limits (L.L and P.L.) and plasticity index (P.I.), the lowest swelling, tenacity and cohesion, the largest grain size and thus the highest permeability among other clay minerals.

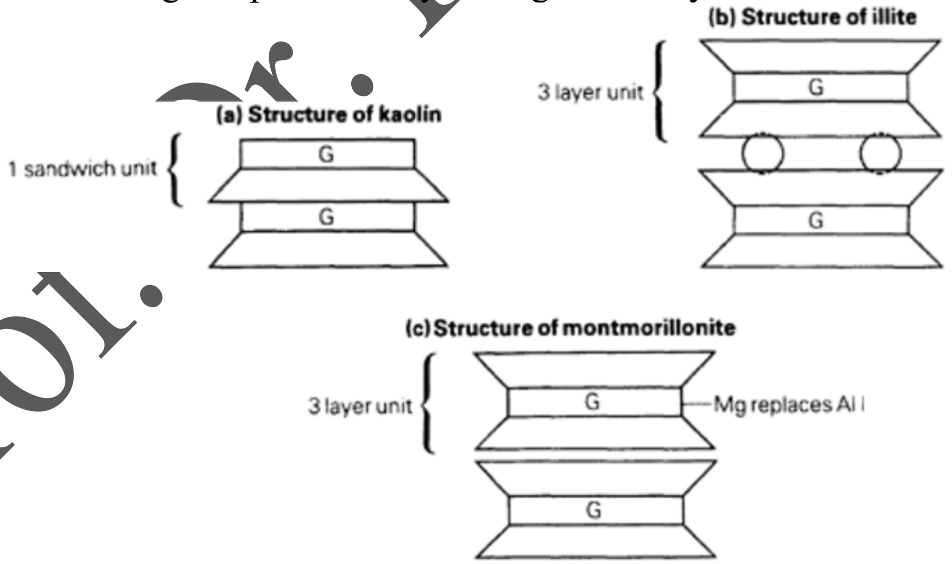


Fig. (5.3). Diagram of the structures of (a) kaolinite ; (b) illite ; and (c) montmorillonite .

b- Illite Group: $KAl_2(AlSi_3)O_{10}(OH)_2$

Illite consists of a gibbsite sheet bonded to two silica sheets- one at the top and another at the bottom (Fig. 5.3b). Illite, like the micas, is termed a 2:1 sheet silicate since one sandwich unit consists of two silica layers with one gibbsite layer between. The units are joined or bonded by potassium ions (K^+ ions). It is sometimes called clay mica. The negative charge to balance the potassium ions comes from the substitution of aluminum for some silicon in the tetrahedral sheets. Substitution of one element for another with no change in the crystalline form is known as ***isomorphous substitution.*** Its engineering properties of liquid-plastic limits (L.L and P.L.), plasticity index (P.I.), swelling, tenacity, cohesion, grain size and permeability are intermediate between those of kaolinite and montmorillonite.

C- Montmorillonite: $[2Al_2(AlSi_3)O_{10}(OH)_2]^{2-}$

Montnnrillonite has a structure similar to that of illite - that is, one gibbsite sheets and sandwiched between two silica sheets (Fig. 5.3c). In montmorillonite the units are held together by H^+ ions and occasional Na^+ ions. In the gibbsite layer Al can be replaced by Mg. Montmorillonite is a member of the smectite clays and is also a 2:1 sheet silicate similar to illite. The structure of montmorillonite is similar to that of vermiculite. In the latter the main octahedral layers are brucite (with some Al replacing Mg). Chlorite is also a sheet silicate, but is termed a 2:2 sheet silicate since two silica layers are joined to two brucite or gibbsite ones. ln montmorillonite there is isomorphous substitution of magnesium and iron for aluminum in the octahedral sheets-potassium ions are not present as in illite, and a large amount of water is attracted into the space between the layers. Commercially, It is called bentonite. From engineering point of view, it is considered to have the highest liquid- plastic limits (L.L and P.L.) and plasticity index (P.I.), the highest swelling, tenacity and cohesion, the smallest grain size and thus the lowest permeability among other clay minerals.

Besides kaolinite, illite, and montmorillonite, other common clay minerals generally found are chlorite, halloysite, vermiculite, and attapulgite.

5.3.3 Classification of Soils with respect to Salts

Soils are classified according to the salt contents into:

a- Saline Soils: Those soils contain sodium salts (sodium chloride and sulphates), and are presented in arid regions with shallow groundwater table. With the evaporation of soil moisture, the dissolved salts are precipitated forming soils rich in these salts.

b- Alkaline Soils: Those soils contain sodium carbonates and are characterized by the presence of shrinkage cracks resulting from drought.

5.3.4 Soil Improvement

Soil degradation is a concern worldwide. We have noted that salts arise to the near-surface soil by evaporation and capillary action processes besides, desertification, erosion, and other chemical modification by human activity all contribute to reduce soil quality, fertility, and productivity. The problems are widespread; the contributing causes vary regionally. Different methods have been applied to improve the soil chemistry:

1- Application of fertilizers, herbicides, and pesticides is another way that soil composition is changed, in this case by the addition of a variety of compounds through human activities.

2- In dry climates, for example, irrigation water may dissolve salts in soils; as the water evaporates near the surface, it can redeposit those salts in near-surface soil from which they had previously been leached away. As the process continues, enough salt may be deposited that plant growth suffers.

3- It is preferable to cover soil surface with clean alluvial sand.

4- Adding predetermined amount of gypsum which acts as a diluter and purifier but it is uneconomic.

4- Base exchange by adding calcium bicarbonates $[Ca(HCO_3)_2]$ to the soil.

5- The most preferred method is lowering groundwater table by drainage system to carry excess runoff from the extensively irrigated land.

5.3.5 Soil of Iraq

Soil of Iraq is varied from place to place due to the variation in the original material from which it forms, climatic and vegetation changes. Thus soil of Iraq is subdivided into:

1- Mountainous Soil: It is a residual type of soil resulted from chemical weathering and characterized by the presence of all horizons of the soil profile. This soil is poor in salts and thick especially in the valleys. Moreover, it is characterized by swelling and cracking due to the presence of montmorillonite clay mineral. In the upper part of Al-Jazira area, the soil is mainly formed from gypsum, sandstone, and limestone. While the soil adjacent to mountain belts, it contains higher amounts of calcareous material than the gypseous one due to erosion of calcareous rocks.

2- Mesopotamian Soil: It is thick soil contains recent silt deposits and characterized by its layering and its richness in salts (such as calcium carbonates and sulphates). The groundwater table in this area is shallow and the main clay minerals are montmorillonite and illite. This type of soil is used in the manufacture of bricks and cement.

3- Desert Soil: This type of soil is formed by mechanical weathering by wind. It consists mainly sand covering gypseous deposits at shallower depths. Thus, it consists of gypsum with high amount of salts.

REVIEW QUESTIONS

5.1 If two identical rocks were weathered, one mechanically and the other chemically, how would the products of weathering for the two rocks differ?

5.2 Briefly explain how the rate of chemical weathering is related to:
a- the amount of precipitation.
b- the temperature, and
c- the amount of mechanical weathering.

5.3 How does mechanical weathering add to the effectiveness of chemical weathering?

5.4 Granite and basalt are exposed at the surface in a hot, wet region.
a- Which type of weathering will predominate?
b- Which of the rocks will weather most rapidly? Why?

5.5 Heat speeds up a chemical reaction. Why then does chemical weathering proceed slowly in a hot desert?

5.6 How is carbonic acid (H_2CO_3) formed in nature? What results when this acid reacts with potassium feldspar?

5.7 What factors might cause different soils to develop from the same parent material, or similar soils to form from different parent materials?

5.8 Which of the controls of soil formation is most important? Explain.

5.9 List the characteristics associated with each of the horizons in a well-developed soil profile. Under what circumstances do soils lack horizons?

5.10 How can slope affect soil development?

5.11 Soils formed in the humid tropics and the Arctic both contain little organic matter. Do both lack humus for the same reasons?

5.12 Sketch a generalized soil profile and indicate the **A**-horizon , **B**-horizon, **C**-horizon, and zone of bedrock. Is such a profile always occur and why?

5.13 Define the term "bedrock".

5.14 Contrast between stalactites and stalagmites.

6. Geological Materials Used in Construction

6.1 Introduction

Stone has been used as a construction material because of:

1. Local availability **2.** Requires little energy for extraction and processing. **3.** For building purposes as rocks or sand and gravel. **4.** Construction materials for road and concrete construction.

6.2 Types of Aggregates

Aggregates can be classified into crushed and natural aggregates.

a- Crushed Rocks

Rocks which have been crushed and produced for a number of purposes, the chief of which are for concrete and road aggregate. Crushed aggregates have the following characteristics:

1. Angular rocks are better for roadstone.
2. Quality control is simple where a single rock mass is being quarried.
3. Impurities are easily removed by screening.
4. Main costs are for blasting and crushing.
5. Selection often based on distance from quarry to site; transport costs.

b- Natural Aggregates

Natural aggregates include all the natural rocks without crushing which have the following characteristics:

1. Alluvial gravels are the most important resource from floodplain and terraces.
2. River, marine and glacial gravels are also used.
3. Quality control is more difficult.
4. Main costs are for overburden stripping and screening.

6.3 Factors Affecting Building Rocks

A number of factors determine whether a rock will be worked as a building stone. These include:

1. The volume of material that can be quarried: As far as volume is concerned, the life of the quarry should be at least 20 years. The amount of overburden that has to be removed also affects the economics of quarrying.

2. The ease with which it can be quarried: The ease with which a rock can be quarried depends on geological structures, notably the geometry of joints and bedding planes. Ideally, rock for building stone should be massive, certainly it must be free from closely spaced joints or other discontinuities as these control block size. In the case of ***sedimentary rocks***, where beds dip steeply, quarrying has to take place along the strike. Steeply dipping rocks can also give rise to problems of slope stability when excavated. On the other hand, if beds of rock dip gently, it is advantageous to develop the quarry floor along the bedding planes. The massive nature of igneous rocks such as granite means that a quarry can be developed in any direction, within the constraints of planning permission.

3. The wastage due to quarrying: Weathered rock represents waste therefore the ratio of fresh to weathered rock is another economic factor.

4. The cost of transportation

5. Appearance: A uniform appearance is generally desirable in building stone. The appearance of a stone largely depends on its color, texture and its mineral composition. Generally speaking, rocks of light color are used as building stone.

6. Physical Properties

a. Texture and porosity: The texture and porosity of a rock affect its ease of dressing, and the amount of expansion. For example, fine-grained rocks are more easily dressed than coarse varieties. The retention of water in a rock with small pores is greater than in one with large pores and so they are more prone to frost attack.

b. Strength: For usual building purposes, a compressive strength of 35 MPa is satisfactory. In certain instances, tensile strength is important which may be generated in a stone subjected to ground movements. The tensile strength of a rock is a fraction of its compressive strength. Hardness is a factor of small consequence, except where a stone is subjected to continual wear, such as in steps or pavings.

c. Durability: The durability of a stone is a measure of its ability to resist weathering over an extensive period of time. It is one of the most important factors that determine whether or not a rock will be worked for building stone. This test involves immersing specimens for 10 days in sulphuric acid. Stones that are unaffected by the test are regarded as being resistant to attack by acidic rainwater. Those stones that fail are not recommended for external use in polluted environments.

6.4 Damages in Rocks

Damages can occur to stone by different causes, these are:

1. Alternate wetting and drying: Water in the pores of a stone of low tensile strength can expand enough when warmed to cause its disruption.

2. Frost: Frost damage is one of the major factors causing deterioration in a building stone. As water turns to ice, it increases in volume, thus giving rise to an increase in pressure within the pores. Usually, coarse-grained rocks withstand freezing better than the fine-grained types. In other words, rocks with larger mean pore diameters allow outward drainage and escape of moisture, therefore, are less frost susceptible.

3. Deleterious salts: Salts, such as halite ($NaCl$); gypsum ($CaSO_4.2H_2O$), anhydrite ($CaSO_4$) and soluble salts ($NaCl$, $NaSO_4$, $MgSO_4$), in a building stone are generally derived from the ground or the atmosphere or in the pores of the parental rock. Their presence in a stone gives rise to different effects (Fig.6.1). They may cause

a. Efflorescence by crystallizing on the surface of a stone.

b. Pressures produced by crystallization of salts or soluble salts in small pores are appreciable (of about 100-200 MPa) and are often sufficient to cause stone powdering, cavities and disruption.

c. Disruption in stone also may take place due to thermal expansion of salts in the pores.

Fig. (6.1). A cavity formed in magnesian limestone, parish church, England.

4. The rate of weathering: The rate of weathering of silicate rocks is usually slow. Building stones from igneous rocks generally suffer negligible decay in climates, while stones from sedimentary rocks may undergo a varying amount of decay. In urban atmospheres, where weathering is accelerated due to the presence of aggressive impurities such as SO_2, SO_3, NO_3, Cl_2 and CO_2 in the air, which produce corrosive acids. Limestones are the most suspect when weak sulphuric acid reacts with the calcium carbonate of limestones to produce calcium sulphate which have a dramatic effect on the appearance of buildings (Fig. 6.2). The best type of stones for external use is sandstones (mainly quartz that is well bonded with siliceous cement and low porosity).

5. Exposure of a stone to intense heating: It causes expansion of its minerals with subsequent exfoliation at its surface.

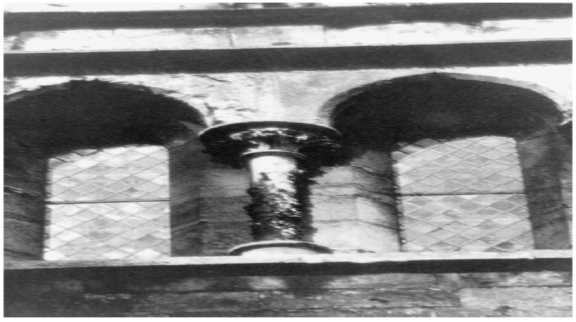


Fig. (6.2). Black crust developed on a column of limestone, Lincoln cathedral, Lincoln, England.

6.5 Methods of Quarrying Building Rocks

1. Stone may be obtained by splitting along the bedding and/or joint surfaces by using wedges.

2. Stone also may be cut from the quarry face by using a wire saw or diamond wire.

3. Explosives are used along joint and/or bedding planes, and not fracture the material. The object is to obtain blocks of large dimensions that can be sawn to size.

Granite is ideally suited for building over 100 years ago, for engineering purposes as it has exceptional weathering properties, and most granites are virtually indestructible under normal climatic conditions. But the sign of deterioration becomes apparent if the polished granite is such the exposed to very heavily polluted atmospheres, for a considerable length of time. The maintenance cost of granite as compared with other materials is therefore very much less and, in most cases, there is no maintenance cost at all for a considerable number of years.

Limestones show a variation in their color, texture and porosity, and those that are fossiliferous are highly attractive when cut and polished. However, carbonate stone can undergo dissolution by acidified water, surface discoloration and structural weakening (Fig.6.3).

Sandstones: The color and strength of ***sandstone*** are largely attributable to the type and amount of cement binding the constituent grains. The cement content also influences the porosity and, therefore, water absorption.

Fig. (6.3). Weathered limestone gargoyle and scabbing of stone, Seville cathedral, Spain.

6.6 Uses of Rocks

1. Roofing and Facing Materials

Rocks used for facing stones should have a high tensile strength in order to resist cracking. The high tensile strength also means that thermal expansion is not a great problem when slabs are spread over large faces. Rocks used for roofing purposes must split into thin slabs, in addition to being durable and impermeable. Consequently, slate is one of the best roofing materials available and has been used extensively.

Slates are derived from argillaceous rocks when were metamorphosed. They are characterized by their cleavage, which allows the rock to break into thin slabs. Slates are differently colored. They have high specific gravity and density with low water absorption. There is a large amount of wastage when explosives are used to quarry slate. Accordingly, they are sometimes quarried by using a wire saw. Slates slabs may split into slate tiles by hand (Fig.6.4). If ***granite or syenite*** is used as a facing stone, then it should not be overdried, but should retain some quarry sap, otherwise it becomes too tough and hard to fabricate.

Fig. (6.4). Coarse-grained "greenslate" being split by hand for facing stone, England.

2. Armourstone

Armourstone refers to large blocks of rock that are used to protect civil engineering structures. Large blocks of rock, which may be single-size or, more frequently, widely graded (rip-rap), are used. Usually, armourstone is specified by weight, a median weight of between 1 and 10 tonnes normally being required. Blocks up to 20 tonnes, however, may be required for breakwaters that will be subjected to large waves. They are used to:

a. protect the upstream face of dams against wave action.
b. in the construction of river bank and bed protection and stabilization,
c. as well as in the prevention of scour around bridge piers.
d. in coastal engineering for the construction breakwaters, embankments,
e. protection of sea walls, and for rubble rock groynes.

3. Crushed Rock: Concrete Aggregate

Crushed rock is produced for a number of purposes, the chief of which are for concrete and road aggregate (Fig. 6.5). Approximately 75% of the volume of concrete consists of aggregates, therefore its properties have a significant influence on the engineering behavior of concrete. Aggregate is divided into coarse (40 mm and larger than 4 mm in size) and fine types (less than 4 mm in size). The amount of overburden that has to be removed is an important factor in quarrying operations, for if this increases and is not useable, then a time comes when quarrying operations become uneconomic.

Fig. (6.5). Quarrying granite for aggregate, Hong Kong.